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A

NEW TREATISE

ON THE

USE OF THE GLOBES;

OR,

A PHILOSOPHICAL VIEW

OF

THE EARTH AND HEAVENS:

COMPREHENDING

AN ACCOUNT OF THE FIGURE, MAGNITUDE, AND MOTION OF THE EARTH;
WITH THE NATURAL CHANGES OF ITS SURFACE, AND THE PRINCIPLES
OF METEOROLOGY AND ASTRONOMY.

PRECEDED BY

AN EXTENSIVE SELECTION OF ASTRONOMICAL AND OTHER DEFINITIONS;
AND ILLUSTRATED BY A GREAT VARIETY OF PROBLEMS,
QUESTIONS FOR THE EXAMINATION OF THE STUDENT, ETC. ETC.

Designed for the Instruction of Youth.

BY THOMAS KEITH.

CA·BODLEI

A NEW EDITION, GREATLY ENLARGED AND IMPROVED.

LONDON:
LONGMAN, BROWN, GREEN, AND LONGMANS,
1848.

London:
Spottiswoode and Shaw,
New-street-Square.

PREFACE.

In preparing for the press the present edition of Mr. Keith's popular *Treatise on the Use of the Globes*, the editors, without departing from the plan of the author, have found it necessary to make numerous additions and alterations. Those parts of the original treatise which were behind the present state of science, have been so revised as to present to the reader a brief, but, it is hoped, an intelligible outline of the important discoveries recently made in ASTRONOMY and PHYSICAL GEOGRAPHY; while the copious additions, either in the form of notes or of distinct chapters, supply the omissions which rendered the original treatise defective as a book of instruction and general information.

The Astronomical Definitions and Geographical Theorems, contained in the *first* chapter, have been retained in the form in which they were originally drawn up by the author; and to the third, fourth, and fifth chapters, it has been considered necessary to add only full explanatory notes. The *second* chapter, with the exception of that portion which relates to the *Laws of Motion*, as well as the remaining chapters of the FIRST PART, have been almost entirely re-written. The *fifth* chapter will be found to contain a sketch of the present state of Hydrographical Science, including a notice of the researches of Sir James Clark Ross, in his late Antarctic expedition. The *seventh* refers to the natural changes on the surface of the earth, comprising a description of mountains, volcanic eruptions, earthquakes, and thermal springs; the *eighth* gives an account of the Atmosphere, including storms and winds; the *ninth* treats of Meteorology; and the *tenth*, of Climate, and the circumstances which modify it.

The SECOND PART of the work, which treats of the elementary principles of Astronomy, has been entirely re-written, although the original arrangement has been preserved as closely as possible, consistently with the necessary alterations. The fourth chapter, which is almost entirely new, contains an account of the later discoveries in Sidereal Astronomy. In the chapter on the Solar System, in which great alterations have been made, an account is given of the planet Neptune, and the recently discovered asteroids, as well as a view of the various theories of astronomers respecting the Solar System. In the sixth chapter a full history and explanation of the Gregorian calendar is for the first time introduced. Numerous other alterations and additions will be found on reference to the work itself.

The THIRD PART, or that containing the Problems performed by the Globes, has undergone a complete revision. Some of the rules which were deemed too verbose have been pruned of their redundancies, and a more concise and clear style of expression generally adopted; while in several an improved method of working the problems has been introduced. Upwards of four hundred questions have been added to the present edition. These additional questions, which will be found distributed under the various rules, have been selected with great care and discrimination, and will, it is hoped, remove any objection that might have been raised against the insufficiency of examples contained in the work, especially in schools.

There have likewise been added tables of the sun's declination, and the fixed stars mentioned in the problems containing their names, the constellations they belong to, with their right ascension and declination. These, it is thought, will greatly assist young persons in working the problems on the celestial globe.

In giving to this treatise a much more extended character, and in entering more fully than hitherto into the subject of Physical Geography, the editors believe that the present edition will be found not only better adapted for the purposes of instruction in the hands of a teacher, but at the same time more useful and interesting to the pupil. New Plates have been added to the work, and improvements made in the old ones.

The First Part of the present edition has been revised by Alfred S. Taylor, F. R. S., Lecturer on Chemistry, &c. in Guy's Hospital.

The Second Part by R. A. Le Mesurier, B.A., Scholar of Corpus Christi College, Oxford.

The Third Part by J. Middleton, Professor of Astronomy, Kensington.

March, 1848.

ORIGINAL PREFACE.

Amongst the various branches of science studied in our academies, and places of public education, there are few of greater importance than that of the Use of the Globes. The earth is our destined habitation, and the heavenly bodies measure our days and years by their various revolutions. Without some acquaintance with the different tracts of land, the oceans, seas, &c. on the surface of the terrestrial globe, no intercourse could be carried on with the inhabitants of distant regions, and consequently their manners, customs, &c. would be totally unknown to us. Though the different tracts of land, &c. cannot be so minutely described on the surface of a terrestrial globe as on different maps, yet the globe shows the figure of the earth, and the relative situations of the principal places on its surface, more correctly than a map. Had the ancients paid no attention to the motions of the heavenly bodies, historical facts would have been given without dates, and we should have had neither dials, clocks, nor watches. To the celestial observations of Eudoxus, Hipparchus, &c., we are indebted for the knowledge of the precession of the equinoxes. Without some acquaintance with the celestial bodies, our ideas of the power and wisdom of the Creator would be greatly circumscribed and confined. The learned and pious Dr. Watts observes, "What wonders "of wisdom are seen in the exact regularity of the revolutions of the heavenly bodies! Nor was there ever any "thing that has contributed to enlarge my apprehensions of "the immense power of God, the magnificence of his creation, and his own transcendent grandeur, so much as the "little portion of astronomy which I have been able to "attain. And I would not only recommend it to young "students, for the same purposes, but I would persuade all "mankind, if it were possible, to gain some degree of ac-

"quaintance with the vastness, the distances and the motions "of the planetary worlds, on the same account."

Dr. Young, in his Night Thoughts, says,

> "An undevout astronomer is mad."

There is scarcely a writer on the different branches of education who has not expressly recommended the study of the globes. Milton observes, that "ere half the school "authors be read, it will be seasonable for youth to learn "the use of the globes." Yet, notwithstanding the importance of the subject, it is entirely neglected in our public schools: and in many of our private academies it has been frequently imperfectly taught: probably for want of a treatise sufficiently comprehensive in its object, and illustrated by a suitable number of examples.

There are several treatises on the globes extant, but they have been chiefly written by mathematical instrument-makers*, or by teachers unacquainted with mathematics.

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* The principal globe-makers in London, are Cary, Bardin, Newton, and Addison.

Cary's globes are 21, 18, 15, 12, 9, and 6 inches in diameter, and the celestial globe may be purchased either with or without the hieroglyphical figures depicted on the surface.

Bardin's globes, or, as they are usually called, the New British Globes, are 18 inches, and 12 inches in diameter.—The New British Globes, manufactured under the direction of *Messrs. W. and S. Jones*, Holborn, are particularly recommended by Mr. Vince, in vol. i. page 569. of his complete System of Astronomy, and were introduced into the Royal Observatory at Greenwich, by the late *Dr. Maskelyne*.

Newton's globes are 15 inches, and 12 inches in diameter. The horizon on these globes is the same as on Bardin's; only, instead of the signs of the zodiac, the ecliptic and zodiacal constellations are introduced. The analemma on the surface is not essentially different from that on Cary's globes.

Addison's globes are 18, 12, and 10 inches in diameter. The analemma on the surface of these globes is the same as the analemma on Cary's globes. *Mr. Addison* has constructed a superb pair of globes, 36 inches in diameter, price 60 guineas.

or separate, { the terraqueous, 35 guineas,
— celestial - 30 guineas.

General Prices of Globes.

21 inches in diameter,	from 10 to 19 guineas,	*Cary.*
18 - - - -	8 to 16 - - -	*Cary, Bardin, Addison.*
15 - - - -	6 to 12 - - -	*Newton, Cary.*
12 - - - -	3½ to 6 - - -	*Cary, Bardin, Newton, Addison.*
10 - - - -	3 to 5 - - -	*Addison.*
9 - - - -	3 to 4½ - - -	*Cary.*
6 - - - -	2½ to £3 18*s.*	*Cary.*

The works of the former must be defective, for want of practice in the art of teaching; and many of the productions of the latter are too puerile and trifling to be introduced into a respectable academy. Youth learn nothing effectually, but by frequent repetition; a multiplicity of examples therefore becomes absolutely necessary; but these examples should be so varied, and the mode of proposing the questions so diversified, as to give the scholar room for the exertion of his faculties, or otherwise no impression will be made on his mind. Treatises on the globes are generally either without any practical exercises, or the exercises are so similar, that when the pupil has finished one of them, the rest may be performed without the trouble of thinking. Examples of this kind may serve to pass away the time, but they will never instruct the scholar.

Had any mathematical writer of note furnished the student with a treatise on the globes, the following work would probably have never appeared; but it rarely happens that the man of science, whose whole time is employed in abstruse researches, will stoop to the humble task of accommodating himself to the capacity of a learner. To a man in the habit of contemplating the writings of a Newton, or travelling in the dry and difficult paths of abstract knowledge, a treatise on the globes is a mere plaything, a trifle not worth notice; as at one glance he sees and comprehends every problem that can be performed by them. Such a man would acquire no credit by writing a Treatise on the Globes; for, notwithstanding the utility of the subject, its simplicity would leave no room for him to display his abilities: the task, therefore, necessarily devolves on writers of a more humble rank.

The ensuing Treatise has been formed entirely from the practice of Instruction, and is arranged in the following order:

PART I. The definitions are very extensive, and, it is hoped, sufficiently plain and clear. Where the name of any ancient author occurs, the time in which he flourished, and his country, are generally mentioned in a note; this practice is followed throughout the book. The table of climates has been newly calculated, and the principle of calculation is given at full length. The *first chapter* likewise contains a table of the constellations, with the fabulous history of several of them: the Greek alphabet, &c. If the definitions, geographical theorems, &c. in this chapter be well explained by the tutor, it is presumed that the scholar will derive considerable advantage. The *second chapter* contains the general properties of matter, and the laws of motion, as preparatory to the reading of the third and fourth chapters; which would otherwise be less intelligible. To the *third* and *fourth chapters* are added some useful notes, which ought to be attended to by those students who are acquainted with arithmetic. The *fifth chapter* treats of springs, rivers, and the saltness of the sea, the *sixth* of the tides; and the *seventh* of earthquakes, &c. with their effects and causes. The subject of the *eighth chapter* is the atmosphere, and of the *ninth*, meteorology. From each of these chapters, it is hoped, the student will derive some useful information.

It has not been usual to introduce several of the aforesaid subjects into a Treatise on the Globes. An intelligent reader will, however, readily admit them to be less extraneous, equally entertaining, and more instructive than scraps of poetry, historical anecdotes, &c. with which some of our Treatises on the Globes abound. Poetical scraps seldom elucidate either mathematical or philosophical subjects, and generally divert the attention of the student from the main object of his pursuit.

PART II. This part comprehends the elementary principles of Astronomy, including an account of the solar system. These ought to be clearly understood by the young student before he attempts to solve many of the problems in the succeeding parts of the book. The object in learning the Use of the Globes should be to illustrate some of the most important branches of geography and astronomy; and this object cannot be attained by merely twirling the globe round and working a few problems, without understanding the principles on which their solutions are founded. Lessons thoroughly explained and clearly understood make a lasting impression on the student's memory, and will enable him, not only to solve such problems as he may meet with in books on the globes, but to frame several new problems himself, and to solve others which he never heard of before.

In the notes attached to this part of the following work, the distances, magnitudes, &c. of the planets are all accurately calculated. This laborious task the author would gladly have avoided, but he found the accounts of the distances, magnitudes, &c. of the planets so variable and contradictory, even in astronomical works of repute, and frequently in the same author, that he conceived such notes as he has introduced would be very useful to a learner.

PART III. contains an extensive collection of Problems; illustrated by a great number of useful examples, many of which are elucidated with notes of considerable importance.

PART IV. comprehends a miscellaneous selection of Problems and Questions for the examination of the student. These questions will be found very useful, and may be extended with advantage by the tutor.

TO CONCLUDE. The author apprehends that he has omitted nothing of importance that particularly relates to the subject, and he hopes, at the same time, that this work will be found to contain little or no extraneous matter. He has endeavoured to supply the young student with a Treatise on the Globes, which may not be unworthy of attention, as a work of science, yet sufficiently plain and intelligible. To those who may object to the smallness of the type, and the closeness of the printing, the author has to observe, that had the work been printed on a larger type, it would have made an octavo volume consisting of at least six hundred pages; the purposes for which it is designed would have been completely defeated; the price doubled; and the book, from its size, rendered less convenient and useful.

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ERRATA.

Page 90. line 20. of note, *for* "and with it," *read* "and it."
128. lines 1 and 6 of note, *for* "Guy," *read* "Gay."
129. last line of text, *for* "had," *read* "having."
130. line 2. from bottom, *for* "father's," *read* "father."

A NEW

TREATISE

ON

THE USE OF THE GLOBES,

&c.

PART I.

DEFINITIONS AND INTRODUCTORY SUBJECTS.

CHAPTER I.

Explanation of the Lines on the Artificial Globes, including Geographical and Astronomical Definitions; with a few Geographical Theorems.

1. THE TERRESTRIAL GLOBE is an artificial representation of the earth. On this globe the four great divisions of the world, the different empires, kingdoms, and countries; the chief cities, seas, rivers, &c., are truly represented, according to their relative situation on the real globe of the earth. The diurnal motion of this globe is from west to east.

2. The CELESTIAL GLOBE is an artificial representation of the heavens, on which the stars are laid down in their natural situations. The diurnal motion of this globe is from east to west, and represents the apparent diurnal motion of the sun, moon, and stars. In using this globe, the student is supposed to be situated in the centre of it, and viewing the stars in the concave surface.

3. The AXIS OF THE EARTH [see *Plate* I. **Figures* I.

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* Figure I. represents the frame of the Globe, with the horizon, brass meridian, and axis: Figure II. the globe itself, with the lines on its surface.

and II.] is an imaginary line passing through its centre, upon which it is supposed to turn, and about which all the heavenly bodies appear to have a diurnal revolution. This line is represented by the wire which passes from north to south, through the middle of the artificial globe.

4. The POLES OF THE EARTH are the two extremities of the axis, where it is supposed to cut the surface of the earth, one of which is called the north, or arctic pole; the other the south, or antarctic pole. The celestial poles are two imaginary points* in the heavens, exactly above the terrestrial poles.

5. The BRAZEN MERIDIAN is the circle in which the artificial globe turns, and is divided into 360 equal parts called degrees.† In the upper semicircle of the brass meridian these degrees are numbered from 0 to 90, from the equator towards the poles, and are used for finding the latitudes of places. On the lower semicircle of the brass meridian they are numbered from 0 to 90, from the poles towards the equator, and are used in the elevation of the poles.

6. GREAT CIRCLES divide the globe into two *equal* parts, as the equator, ecliptic, and the colures.

7. SMALL CIRCLES divide the globe into two unequal parts, as the tropics, polar circles, parallels of latitude, &c.

8. MERIDIANS, or Lines of Longitude, are *semicircles*, extending from the north to the south pole, and cutting the equator at right angles. Every place upon the globe is supposed to have a meridian passing through it, though there be only 24 drawn upon the terrestrial globe; the deficiency is supplied by the brass meridian. When the sun comes to

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* The polar-star is a star of the second magnitude, near the north pole, in the end of the tail of the Little Bear. Its right ascension, for the beginning of the year 1840, was 1h. 2m. 10·683 s.; and its declination 88° 27′ 21·94″ N. — *Nautical Almanac for* 1840.

† Every circle is supposed to be divided into 360 equal parts called degrees, each degree into 60 equal parts called minutes, each minute into 60 equal parts called seconds, &c.; a degree is therefore only a relative idea, and not an absolute quantity, except when applied to a great circle of the earth, as to the equator or to a meridian, in which cases it is 60 geographical miles, or 69·1 English miles. A degree of a great circle in the heavens is a space nearly equal to twice the apparent diameter of the sun; or to twice that of the moon when considerably elevated above the horizon.

Degrees are marked with a small cipher, minutes with *one* dash, seconds with *two*, thirds with *three*, &c. Thus, 25° 14′ 22″ 35‴ are read 25 degrees, 14 minutes, 22 seconds, 35 thirds.

the meridian of any place, it is noon or mid-day at that place.

9. The FIRST MERIDIAN is that from which geographers begin to count the longitudes of places. In English maps and globes the first meridian is a semi-circle supposed to pass through the Royal Observatory at Greenwich.

10. The EQUATOR is a great circle of the earth, equi-distant from the poles: it divides the globe into two hemispheres, northern and southern. The latitudes of places are counted *from* the equator, northward and southward, and the longitudes of places are reckoned *upon* it eastward and westward. The equator, when referred to the heavens, is called the *equinoctial*, because when the sun appears in it, the days and nights are equal all over the world, viz. 12 hours each. The declinations of the sun, stars, and planets, are counted *from* the equinoctial northward and southward, and their right ascensions are reckoned *upon* it eastward round the celestial globe from 0 to 360 degrees.

11. The ECLIPTIC is a great circle in which the sun makes his apparent annual* progress among the fixed stars, and is therefore sometimes called the *via solis* or sun's path; but more properly it is the track which the earth would appear to describe if viewed from the centre of the sun, and is hence denominated the heliocentric circle of the earth. It is named the ecliptic, because eclipses can only happen when the moon appears to be in or very near to this circle. The ecliptic cuts the equinoctial at an angle of 23° 28′; the points of intersection are called the equinoctial points.

12. The ZODIAC, on the celestial globe, is a space which extends about nine degrees on each side of the ecliptic, like a belt or girdle, within which the motions of all the planets† are performed.

13. SIGNS OF THE ZODIAC. The ecliptic and zodiac are divided into 12 equal parts, called signs, each containing 30 degrees. The sun makes his apparent annual progress through the ecliptic at the rate of nearly a degree in a day.

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* The sun's apparent *diurnal path* is either in the equinoctial, or in lines nearly parallel to it; and his apparent *annual path* may be traced in the heavens, by observing what particular constellation in the zodiac is on the meridian at midnight; the opposite constellation will show, very nearly, the sun's place at noon on the same day.

† Except three of the newly discovered minor primary planets, viz. *Ceres*, *Pallas*, and *Juno*.

The names of the signs, and the days on which the sun enters them, are as follow:—

Spring Signs.

♈ *Aries*, the Ram, 21st of March.
♉ *Taurus*, the Bull, 19th of April.
♊ *Gemini*, the Twins, 20th of May.

Summer Signs.

♋ *Cancer*, the Crab, 21st of June.
♌ *Leo*, the Lion, 22d of July.
♍ *Virgo*, the Virgin, 22d of August.

These are called northern signs, being north of the equinoctial.

Autumnal Signs.

♎ *Libra*, the Balance, 23d of September.
♏ *Scorpio*, the Scorpion, 23d of October.
♐ *Sagittarius*, the Archer, 22d of November.

Winter Signs.

♑ *Capricornus*, the Goat, 21st December.
♒ *Aquarius*, the Water-bearer, 20th January.
♓ *Pisces*, the Fishes, 19th February.

These are called the southern signs.

The spring and autumnal signs are called *ascending* signs; because when the sun is in any of these, his declination is increasing. The summer and winter signs are called descending signs, because when the sun is in any of these, his declination is decreasing.

14. The Colures are two great circles passing through the poles of the world; one of them passes through the equinoctial points, Aries * and Libra; the other through the solstitial points, Cancer and Capricorn; hence they are called the equinoctial and solstitial colures. They divide the ecliptic into four equal parts, and mark the four seasons of the year.

15. Declination of the sun, of a star, or planet, is its distance from the equinoctial, northward or southward. When the sun is in the equinoctial he has no declination, and enlightens half the globe from pole to pole. As he increases in north declination he gradually shines further over the

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* In the time of *Hipparchus* the equinoctial colure is supposed to have passed through the middle of the *constellation* Aries. Hipparchus was a native of Nicæa, a town of Bithynia, in Asia Minor, about 75 miles S. E. of Constantinople, now called Isnic; he made his observations between 160 and 135 years before Christ.

north pole, and leaves the south pole in darkness: in a similar manner, when he has south declination, he shines over the south pole, and leaves the north pole in darkness. The greatest declination the sun can have is 23° 28′; the greatest declination a star can have is 90°, and that of a planet 30° 28′ * north or south.

16. The TROPICS are two small circles, parallel to the equator (or equinoctial), at the distance of 23° 28′ from it; the northern is called the Tropic of Cancer, the southern the Tropic of Capricorn. The tropics are the limits of the torrid zone, northward and southward.

17. The POLAR CIRCLES are two small circles, parallel to the equator (or equinoctial), at the distance of 66° 32′ from it, and 23° 28′ from the poles. The northern is called the *arctic*, the southern the *antarctic* circle.

18. PARALLELS OF LATITUDE are small circles drawn through every ten degrees of latitude on the terrestrial globe, parallel to the equator. Every place on the globe is supposed to have a parallel of latitude drawn through it, though there are generally only *sixteen* parallels of latitude drawn on the terrestrial globe.

19. The HOUR CIRCLE on the artificial globes is a small circle of brass, with an index or pointer fixed to the north pole: it is divided into 24 † equal parts, corresponding to the hours of the day, and these are again subdivided into halves and quarters. The hour circle, when placed *under* the brass meridian, is movable round the axis of the globe, and the brass meridian, in this case, answers the purpose of an index.

20. The HORIZON is a great circle which separates the visible half of the heavens from the invisible; the earth being considered as a point in the centre of the sphere of the

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* Except the minor primary planets, *Ceres*, *Juno*, and *Pallas*, whose orbits are so much inclined to the ecliptic as considerably to exceed the limits of the zodiac.

† Some globes have two rows of figures on the index, others but one. On *Bardin's New British Globes* there is an hour circle at each pole, numbered with two rows of figures. On Adams's common globes there is but one index; and on his improved globes the hours are counted by a brass wire with two indexes standing over the equator. The form of the hour circle is, however, a matter of little consequence (provided it be placed *under* the brass meridian), as the equator will answer every purpose to which a circle of this kind can be applied.

fixed stars. Horizon, when applied to the earth, is either *sensible* or *rational.*

21. The Sensible, or visible horizon, is the circle which bounds our view, where the sky appears to touch the earth or sea. *

22. The Rational, or true horizon, is an imaginary plane, passing through the centre of the earth parallel to the sensible horizon. It determines the rising and setting of the sun, stars, and planets.

23. The Wooden Horizon, circumscribing the artificial globe, represents the rational horizon on the real globe. This horizon is divided into several concentric circles, which on *Bardin's* † *New British Globes* are arranged in the following order:—

The First is marked amplitude, and is numbered from the east towards the north and south, from 0 to 90 degrees, and from the west towards the north and south in the same manner.

The Second is marked azimuth, and is numbered from the north point of the horizon towards the east and west, from 0 to 90 degrees: and from the south point of the horizon towards the east and west in the same manner.

The Third contains the thirty-two points of the compass, divided into half and quarter points. The degrees in each point are to be found in the azimuth circle.

The Fourth contains the twelve signs of the zodiac, with the figure and character of each sign.

The Fifth contains the degrees of the signs, each sign comprehending 30 degrees.

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* The sensible horizon extends only a few miles; for example, if the eye of a spectator supposed out at sea or standing on an extensive plane be elevated 6 feet above the surface of the sea or the plane on which he stands, the utmost extent of his view upon that surface or plane would be about three miles. Thus, if h be the height of the eye above the surface of the sea, and d the diameter of the earth in feet, then $\sqrt{(d+h) \times h}$, will show the distance which a person will be able to see straight forward. (*Keith's* Trigonometry, Seventh Edition. Example XLV. page 82.)

† Cary's Globes have a different division of the wooden horizon. The first circle, or that nearest to the globe, is numbered from the east and west towards the north and south, from 0 to 90°. The second contains the thirty-two points of the compass. The third, the signs of the zodiac. The fourth, the degrees of the signs. The fifth, the days of the months. The sixth, the names of the months. The wooden horizon of Adams's Globes is divided in the same manner.

The Sixth contains the days of the month answering to each degree of the sun's place in the ecliptic.

The Seventh contains the equation of time, or difference of time shown by a well-regulated clock and a correct sundial. When the clock ought to be faster than the dial, the number of minutes, expressing the difference, is followed by the sign + ; when the clock or watch ought to be slower, the number of minutes in the difference is followed by the sign —.

The Eighth contains the twelve calendar months.

24. The Cardinal Points of the horizon are east, west, north, and south.

25. The Cardinal Points in the heavens are the zenith, the nadir, and the points where the sun rises and sets.

26. The Cardinal Points of the ecliptic are the equinoctial and solstitial points, which mark out the four seasons of the year; and the *Cardinal Signs* are ♈ Aries, ♋ Cancer, ♎ Libra, and ♑ Capricorn.

27. The Zenith is a point in the heavens exactly over our heads, and is the elevated pole of our horizon.

28. The Nadir is a point in the heavens exactly under our feet, being the depressed pole of our horizon, and the zenith, or elevated pole, of the horizon of our antipodes.

29. The Pole of any circle is a point on the surface of the globe, 90 degrees distant from every part of that circle of which it is the pole. Thus the poles of the earth are 90 degrees from every part of the equator ; the poles of the ecliptic (on the celestial globe) are 90 degrees from every part of the ecliptic, and 23° 28′ from the poles of the equinoctial, consequently they are situated in the arctic and antarctic circles. Every circle on the globe, whether real or imaginary, has two poles diametrically opposite to each other.

30. The Equinoctial Points are Aries and Libra, where the ecliptic cuts the equinoctial. The point Aries is called the *vernal* equinox, and the point Libra, the *autumnal* equinox. When the sun is in either of these points, the days and nights on every part of the globe are equal to each other.

31. The Solstitial Points are Cancer and Capricorn. When the sun is in, or near, these points, the variation in his greatest or meridian altitude is scarcely perceptible for several days; because *the* ecliptic near these points is almost

parallel to the equinoctial, and therefore the sun has nearly the same declination for several days.—When the sun enters Cancer, it is the longest day to all the inhabitants on the north side of the equator, and the shortest day to those on the south side. When the sun enters Capricorn it is the shortest day to those who live in north latitude, and the longest day to those who live in south latitude.

32. A HEMISPHERE is half the surface of the globe; every *great circle* divides the globe into two hemispheres. The horizon divides the upper from the lower hemisphere in the heavens; the equator separates the northern from the southern on the earth; and the brass meridian, standing over any place on the terrestrial globe, divides the eastern from the western hemisphere.

33. The MARINER'S COMPASS * is a representation of the horizon, and is used by seamen to direct and ascertain the course of their ships. It consists of a circular brass box, which contains a paper card, divided into 32 equal parts, and fixed on a magnetical needle that always turns *towards* the north. Each point of the compass contains 11° 15′ or 11¼ degrees, being the 32d part of 360 degrees.

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* Though the attractive power of the magnet, or loadstone, was known to the Greeks at least as early as the time of Plato and Aristotle, yet the *directive* power of it, or that property whereby it disposes bars of iron or steel touched with it to lie along the plane of the meridian of any place, so as to point *nearly* due North and South, was certainly entirely unknown to them: neither is it satisfactorily proved by whom this property was discovered. By some it is ascribed to Paul the Venetian, who, it is said, first brought into use (about the year 1260) what is now called the Mariner's Compass. By others this instrument is said to have been invented by John Goia, a Neapolitan, in the year 1300; who is also spoken of as the first person who applied it to navigating ships in the Mediterranean.

The *Variation* of the needle, or its declination from the true north and south points, is a much later discovery, and is generally ascribed to Sebastian Cabot, a Venetian, or as some will have it, the son of a Genoese merchant, who resided at Bristol, where Sebastian was born. This discovery was made about the year 1497, previous to which any deviation of the direction of the needle from the plane of the meridian was supposed to arise from some defect in the construction of the particular instrument in which it was observed. The variation of the needle was, as might naturally be expected, long considered constant, or to be invariably the same at the same place; nor was the *variation*, to which what is called *the variation of the needle* is itself subject, fully ascertained till about the year 1625, when, according to Dr. Wallis (Philos. Trans. Nos. 276 — 278.), it was first discovered by Mr. Gillibrand, one of the *professors* at Gresham College. — R.

34. The VARIATION OF THE COMPASS is the deviation of its points from the corresponding points in the heavens. When the north point of the compass is to the east of the true north point of the horizon, the variation is east: if it be to the west, the variation is west.

At present, in England, the needle points about 24° to the westward of the north.

At LONDON in

1576, the variation was,	11°	15′	E.	1790, - - -	23°	39′	W.
1612, - - -	6	10	E.	1794, - - -	23	54	W.
1622, - - -	6	0	E.	1796, - - -	24	0	W.
1634, - - -	4	5	E.	1800, - - -	24	2	W.
1657 to 1662, - -	0	0		1804, - - -	24	8	W.
1666, - - -	1	35	W.	1806, - - -	24	8	W.
1683, - - -	4	30	W.	1820, - - -	24	34	W.
1700, - - -	8	0	W.	1823, - - -	24	10	W.
1722, - - -	14	22	W.	1831, - - -	24	0	W.
1747, - - -	17	40	W.	1842, - - -	23	11	W.
1780, - - -	22	10	W.				

The compass is used for setting the artificial globe north and south; but care must be taken to make a proper allowance for the variation.*

35. LATITUDE OF A PLACE, on the terrestrial globe, is its distance from the equator in degrees, minutes, or geographical miles, &c. and is reckoned on the brass meridian, from the equator towards the north or south pole.

36. LATITUDE OF A STAR OR PLANET, on the celestial globe, is its distance from the ecliptic, northward or southward, counted towards the pole of the ecliptic, on the quadrant of altitude. The greatest latitude a star can have is 90 degrees, and the greatest latitude of a planet is nearly 8 degrees.† The sun being always in the ecliptic, has no latitude.

37. The QUADRANT OF ALTITUDE is a thin flexible piece of brass divided upwards from 0 to 90 degrees, and downwards from 0 to 18 degrees, and when used is generally screwed to the brass meridian. The upper divisions are used to determine the distances of places on the earth, the

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* It will be observed by the above table that, without any assignable cause, the needle pointed due north for five years, 1657 — 1662. What is called the dip of the needle, is its deviation from the horizontal line when suspended so as to swing vertically. This is 70° in this latitude. It points to the seat of magnetic force in the earth.—T.

† The newly discovered planets, or Asteroids, *Ceres* and *Pallas*, &c., do not appear to be confined within this limit.

distances of the celestial bodies, their altitudes, &c., and the lower divisions are applied to finding the beginning, end, and duration of twilight.

38. LONGITUDE OF A PLACE, on the terrestrial globe, is the distance of the meridian of that place from the first meridian, reckoned in degrees and parts of a degree on the equator. Longitude is either eastward or westward, according as the place is eastward or westward of the first meridian. The greatest longitude that a place can have is 180 degrees, or half the circumference of the globe.

39. LONGITUDE OF A STAR, or PLANET, is reckoned on the ecliptic from the point Aries, eastward, round the celestial globe. The longitude of the sun is what is called the sun's place on the terrestrial globe.

40. ALMACANTARS, or parallels of altitude, are *imaginary* circles parallel to the horizon, and serve to show the height of the sun, moon, or stars. These circles are not drawn on the globe, but they may be described for any latitude by the quadrant of altitude.

41. PARALLELS OF CELESTIAL LATITUDE are small circles drawn on the celestial globe parallel to the ecliptic.

42. PARALLELS OF DECLINATION are small circles parallel to the equinoctial on the celestial globe, and are similar to the parallels of latitude on the terrestrial globe.

43. AZIMUTH, or VERTICAL CIRCLES, are imaginary great circles passing through the zenith and the nadir, cutting the horizon at right angles. The altitudes of the heavenly bodies are measured on these circles, which circles may be represented by screwing the quadrant of altitude on the zenith of any place, and making the other end move along the wooden horizon of the globe.

44. The PRIME VERTICAL is that azimuth circle which passes through the east and west points of the horizon, and is always at right angles to the brass meridian, which may be considered as another vertical circle passing through the north and south points of the horizon.

45. The ALTITUDE of any object in the heavens is an arc of a vertical circle, contained between the centre of the object and the horizon. When the object is upon the meridian, this arc is called the meridian altitude.

46. The ZENITH DISTANCE of any celestial object is the arc of a vertical circle, contained between the centre of that object and the zenith; or it is what the altitude of the object

wants of 90 degrees. When the object is on the meridian, this arc is called the meridian zenith distance.

47. The POLAR DISTANCE of any celestial object is an arc of a meridian, contained between the centre of that object and the pole of the equinoctial.

48. The AMPLITUDE of any object in the heavens is an arc of the horizon, contained between the centre of the object when rising, or setting, and the east or west points of the horizon. Or, it is the distance which the sun or a star rises from the east, and sets from the west, and is used to find the variation of the compass at sea. When the sun has north declination, it rises to the north of the east, and sets to the north of the west; and when it has south declination, it rises to the south of the east, and sets to the south of the west. At the time of the equinoxes, when the sun has no declination, viz. on the 21st of March, and on the 23d of September, it rises exactly in the east, and sets exactly in the west.

49. The AZIMUTH of any object in the heavens is an arc of the horizon, contained between a vertical circle passing through the object, and the north or south points of the horizon. The azimuth of the sun, at any particular hour, is used at sea for finding the variation of the compass.

50. HOUR CIRCLES, or HORARY CIRCLES, are the same as the meridians. They are drawn through every 15 degrees* of the equator, each answering to an hour—consequently every degree of longitude answers to four minutes of time; every half degree to two minutes, and every quarter of a degree to *one* minute.

On the globes these circles are supplied by the brass meridian, the hour circle and its index.

51. The SIX O'CLOCK HOUR LINE. As the meridian of any place, with respect to the sun, is called the 12 o'clock hour circle; so that great circle passing through the poles, which is 90 degrees distant from it on the equator, is called by astronomers the six o'clock hour circle, or the six o'clock hour line. The sun and stars are on the eastern half of this circle 6 hours before they come to the meridian; and on the western half six hours after they have passed the meridian.

52. CULMINATING POINT of a star or planet is that point of its orbit which, on any given day, is the most elevated.

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* On *Cary's* large Globes the meridians are drawn through every 10 degrees, as on a Map.

Hence a star or planet is said to culminate when it comes to the meridian of any place; for then its altitude at that place is the greatest.

53. APPARENT NOON is the time when the sun comes to the meridian; viz. 12 o'clock, as shown by a correct sun-dial.

54. TRUE or MEAN NOON, 12 o'clock, as shown by a well-regulated clock, adjusted to go 24 hours in a *mean solar day*.

55. The EQUATION OF TIME at noon is the interval between the true and apparent noon, viz. it is the difference of time shown by a well-regulated clock and a correct sun-dial.

56. A TRUE SOLAR DAY is the time from the sun's leaving the meridian of any place, on any day, till it returns to the same meridian on the next day; viz. it is the time elapsed from 12 o'clock at noon, on any day, to 12 o'clock at noon on the next day, as shown by a correct sun-dial. A true solar day is subject to a continual variation, arising from the obliquity of the ecliptic, and the unequal motion of the earth in its orbit; the duration thereof sometimes exceeds, at others falls short of 24 hours, and the variation is the greatest about the first of November, when the true solar day is 16′ 17″ less than 24 hours, as shown by a well-regulated clock.

57. A MEAN SOLAR DAY is measured by equal motion, as by a clock or time-piece, and consists of 24 hours. There are in the course of a year as many mean solar days as there are true solar days, the clock being as much faster than the sun-dial on some days of the year, as the sun-dial is faster than the clock on others. Thus the clock is faster than the sun-dial from the 24th of December to the 15th of April, and from the 16th of June to the 31st of August: but from the 15th of April to the 16th of June, and from the 31st of August to the 24th of December, the sun-dial is faster than the clock. When the clock is gaining on the sun-dial, the solar day exceeds 24 hours; and when the sun-dial is gaining on the clock, the solar day is less than 24 hours; but when the clock and the sun-dial agree, viz. about the 15th of April, 16th of June, 31st of August, and 24th of December, the solar day is exactly 24 hours.

58. The ASTRONOMICAL DAY is reckoned from noon to noon, and consists of 24 hours. This is called a *natural* day, being of the same length in all latitudes.

59. The ARTIFICIAL DAY is the time elapsed between the sun's rising and setting, and is variable according to the different latitudes of places.

60. The CIVIL DAY, like the astronomical or natural day, consists of 24 hours, but begins differently in different nations. The ancient Babylonians, Persians, Syrians, and most of the eastern nations, began their day at sun-rising. The ancient Athenians and the Jews began their day at sun-setting, which custom is followed by the modern Austrians, Bohemians, Silesians, Italians and Chinese. The Arabians begin their day at noon, like the modern astronomers. The ancient Egyptians and Romans began their day at midnight, and this method is followed by the English, French, Germans, Dutch, Spanish and Portuguese.

61. A SIDEREAL DAY is the interval of time from the passage of any fixed star over the meridian, till it returns to it again : or it is the time which the earth takes to revolve once round its axis, and consists of 23 hours, 56 minutes, 4·09 seconds of mean solar time.

In elementary books of astronomy and the globes, the learner is generally told that the earth turns on its axis from west to east in 24 hours; but the truth is, that it turns on its axis in 23 hours, 56 minutes, 4·09 secs., making about 366 revolutions in 365 days, or a year. The natural day would always consist of 23 hours, 56 minutes, 4·09 secs., instead of 24 hours, if the earth had no other motion than that on its axis; but while the earth has revolved eastward once round its axis, it has advanced nearly one degree* eastward in its orbit. To illustrate this, suppose the sun to be upon any particular meridian at 12 o'clock on any day; in 23 hours, 56 minutes, 4·09 secs., afterwards, the earth will have performed one entire revolution; but it will at the same time have advanced nearly one degree eastward in its orbit, and consequently that meridian which was opposite to the sun the day before, will be now one degree westward of it; therefore the earth must perform something more than one revolution before the sun appears again on the same meridian; so that the time from the sun's being on the meridian on any day, to its appearance on the same meridian the next day, is 24 hours.

62. A SOLAR YEAR, or tropical year, is the time the sun takes in passing through the ecliptic, from the tropic, or

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* The earth goes round the sun in 365¼ days nearly; and the ecliptic, which is the earth's path round the sun, consists of 360 degrees; hence by the rule of three, 365¼ D : 360 deg. :: 1 D : 59′ 8″·3, the daily mean motion of the earth in its orbit, or the *apparent* mean motion of the sun in a day. Hence a clock or chronometer, the index of which performs an exact circuit whilst the earth (or the meridian of an observer) moves over 360° 59′ 8″·3, is said to be adjusted to mean solar time.

equinox, till it returns to it again: and consists of 365 days, 5 hours, 48 minutes, 49 seconds.

63. A SIDEREAL YEAR is the time which the sun takes in passing from any fixed star, till he returns to it again, and consists of 365 days, 6 hours, 9 minutes, 12 seconds; the sidereal year is therefore 20 minutes, 23 seconds longer than the tropical year, and the sun returns to the equinox every year before he returns to the same point of the heavens; consequently the equinoctial points have a retrograde motion.

64. THE PRECESSION OF THE EQUINOXES (or more properly the recession of the equinoxes) is a slow motion which the equinoctial points have from east to west, contrary to the order of the signs, which is from west to east.

This motion, from the best observations, is about 50·1* seconds in a year, so that it would require 25,868 years† for the equinoctial points to perform an entire revolution westward round the globe.

In the time of Hipparchus and the oldest astronomers, the equinoctial points were fixed in Aries and Libra: but the signs which were then in conjunction with the sun, when he was in the equinox, are now a whole sign, or 30 degrees eastward of it; so that Aries is now in Taurus, Taurus in Gemini, &c., as may be seen on the celestial globe. Hence also the stars, which rose and set at any particular season of the year in the time of Hesiod‡, Eudoxus§ and Pliny‖, do not answer to the description given by those writers.

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* In *Woodhouse's* Astronomy, the *mean* annual precession is stated to be 50″·34, and in the new *French* Solar Tables 50″·103.

† For the circumference of the equator is 360 degrees, and 50″·1 : 1 year :: 360 : 25,868 years.

‡ HESIOD was a celebrated Grecian poet, born at Ascra, in Bœotia, supposed to have flourished in the time of Homer; he was the first who wrote a poem on Agriculture, entitled *The Works and the Days*, in which he introduces the rising and setting of particular stars, &c. Several editions of his work are now extant.

§ EUDOXUS was a great geometrician and astronomer, from whom Euclid, the geometrician, is said to have borrowed great part of his elements of geometry. Eudoxus was born at Cnidus, a town of Caria, in Asia Minor; he flourished about 370 years before Christ.

‖ PLINY, generally called Pliny the Elder, was born at Verona, in Italy; he composed a work on natural history in 37 books; it treats of the stars, the heavens, wind, rain, hail, minerals, trees, flowers, plants, birds, fishes, and beasts; besides a geographical description of every place on the globe. Pliny perished by an eruption of Vesuvius, in the 79th year of Christ, from too eager a curiosity in observing the phenomenon.

65. POSITIONS OF THE SPHERE are three: right, parallel, and oblique.

66. A RIGHT SPHERE is that position of the earth where the equinoctial passes through the zenith and the nadir, the poles being in the rational horizon. The inhabitants who have this position of the sphere live at the equator: it is called a right sphere, because the parallels of latitude cut the horizon at right angles. In a right sphere the parallels of latitude are divided into two equal parts by the horizon, and the days and nights are of equal length.

67. A PARALLEL SPHERE is that position the earth has when the rational horizon coincides with the equator, the poles being in the zenith and nadir. The inhabitants who have this position of the sphere (if there be any such inhabitants) live at the poles: it is called a parallel sphere, because all the parallels of latitude are parallel to the horizon. In a parallel sphere the sun appears above the horizon for six months together, and he is below the horizon for the same length of time.

68. AN OBLIQUE SPHERE is that position the earth has when the rational horizon cuts the equator obliquely, and hence it derives its name. All inhabitants on the face of the earth (except those who live exactly at the poles or at the equator) have this position of the sphere. The days and nights are of unequal lengths, the parallels of latitude being divided into unequal parts by the rational horizon.

69. CLIMATE is a part of the surface of the earth contained between two small circles parallel to the equator, and of such a breadth, that the longest day in the parallel of latitude nearest the pole, exceeds the longest day in the parallel nearest the equator, by half an hour, in the torrid and temperate zones, or by a month in the frigid zones; so that there are 24 climates between the equator and each polar circle, and six climates between each polar circle and its pole.

I. CLIMATES between the Equator and the Polar Circles.

Climate.	Ends in Latitude.		Where the longest Day is.		Breadths of the Climates.		Climate.	Ends in Latitude.		Where the longest Day is.		Breadths of the Climates.	
	D.	M.	H.	M.	D.	M.		D.	M.	H.	M.	D.	M.
I.	8	34	12	30	8	34	XIII.	59	59	18	30	1	32
II.	16	44	13	—	8	10	XIV.	61	18	19	—	1	19
III.	24	12	13	30	7	28	XV.	62	26	19	30	1	8
IV.	30	48	14	—	6	36	XVI.	63	22	20	—	—	56
V.	36	31	14	30	5	43	XVII.	64	10	20	30	—	48
VI.	41	24	15	—	4	53	XVIII.	64	50	21	—	—	40
VII.	45	32	15	30	4	8	XIX.	65	22	21	30	—	32
VIII.	49	2	16	—	3	30	XX.	65	48	22	—	—	26
IX.	51	59	16	30	2	57	XXI.	66	5	22	30	—	17
X.	54	30	17	—	2	31	XXII.	66	21	23	—	—	16
XI.	56	38	17	30	2	8	XXIII.	66	29	23	30	—	8
XII.	58	27	18	—	1	49	XXIV.	66	32	24	—	—	3

II. CLIMATES between the Polar Circles and the Poles.

Climate.	Ends in Latitude.		Where the longest Day is.	Breadths of the Climates.		Climate.	Ends in Latitude.		Where the longest Day is.	Breadths of the Climates.	
	D.	M.	Da. M.	D.	M.		D.	M.	Da. M.	D.	M.
XXV.	67	18	30 or 1	—	46	XXVIII.	77	40	120or4	4	35
XXVI.	69	33	60—2	2	15	XXIX.	82	59	150—5	5	19
XXVII.	73	5	90—3	3	32	XXX.	90	—	180—6	7	1

The preceding tables may be constructed by the globes, as will be shown in the problems, but not with that exactness given above. Tables of this kind are generally copied from one author into another, without any explanation of the principles on which they are founded.

Construction of the first Table.

In *plate* IV. *figure* IV. HO represents the horizon, ÆQ the equator, ss *c* ss a parallel of the sun's greatest declination, NO the elevation of the pole or latitude of the place; the angle *c a b* measured by the arc QO, the complement of the latitude; *a b* is the ascensional difference, or the time the sun rises before 6 o'clock, and *b c* the sun's declination. Hence, by Baron Napier's rules (see *Keith's* Spherical Trigonometry), *rad.* × *sine a b* = *cotangent a** (*or tangent* NO) × *tangent b c.*

viz. Tangent of the sun's greatest declination 23° 28′,
Is to radius, sine of 90 degrees;
As sine of the sun's ascensional difference,
Is to tangent of latitude. ——— A general rule.

At the end of the first climate the sun rises ¼ before 6; and in every climate, if you take half the length of the longest day, and deduct 6 hours therefrom, the remainder turned into degrees will give the ascensional difference. Hence the ascensional difference, for the first climate, is fifteen minutes of time, equal to 3° 45′; for the second climate 30 minutes = 7° 30′; for the third climate 45 minutes = 11° 15′; for the fourth climate 1 hour = 15°, &c.

Tangent of 23° 28′.........	9·63761	Tangent of 23° 28′.........	9·63761
Is to radius, sine of 90°...	10·00000	Is to radius, sine of 90°...	10·00000
As sine of 3° 45′..........	8·81560	As sine of 7° 30′..........	9·11570
Is to tang. lat. 8° 34′.....	9·17799	Is to tang. lat. 16° 44′....	9·47809

Construction of the second Table.

The longest day is the 21st of June, when the sun's declination is 23° 28′ north. Count half the length of the day from the 21st June, forward and backward; find the sun's declination answering to those two days in the nautical almanac, or in a table of the sun's declination; add the two declinations together, and divide their sum by 2, subtract the quotient from 90 degrees, and the remainder is the latitude. As the sun's declination is variable, it ought to be taken out of the almanac, or tables, for leap-year and the three following years, a mean of these declinations, used as above, will give the latitude as correctly as the nature of the problem admits of, and in this manner the second table was constructed.— Riccioli (an Italian astronomer and mathematician, born at Ferrara, in the Pope's dominions, 1598), in his *Astronomiæ Reformatæ*, published in 1665, makes an allowance for the refraction of the atmosphere in a table of climates. He considers the increase of days to be by half hours, from 12 to 16 hours; by hours from 16 to 20 hours; by 2 hours, from 20 to 24 hours; and by months in the frigid zones, making the number of the days of each month in the north frigid zone something more than those in the south; but as the refraction of the atmosphere is so extremely variable, that scarcely any two mathematicians agree with respect to the quantity, it is evident that a table of climates, calculated with such an uncertain allowance, can be of no material advantage.

70. A Zone is a portion of the surface of the earth contained between two small circles parallel to the equator, and is similar to the term climate, for pointing out the situations of places on the earth, but less exact; as there are only *five* zones, which have been distinguished by particular names; whereas there are 60 climates.

71. The Torrid Zone extends from the tropic of Cancer to the tropic of Capricorn, and is 46° 56′ broad. This zone was thought by the ancients to be uninhabited, because it is continually exposed to the direct rays of the sun; and such parts of the torrid zone as were known to them were sandy deserts, as the middle of Africa, Arabia, &c.; and these

sandy deserts extend beyond the left bank of the Indus, towards Agimere.

72. The Two TEMPERATE ZONES. The north temperate zone extends from the tropic of Cancer to the arctic circle; and the south temperate zone from the tropic of Capricorn to the antarctic circle. These zones are each 43° 4′ broad, and were called temperate by the ancients, because meeting the sun's rays obliquely, they enjoy a moderate degree of heat.

73. The Two FRIGID ZONES. The north frigid zone, or rather segment of the sphere, is bounded by the arctic circle. The north pole, which is 23° 28′ from the arctic circle, is situated in the centre of this zone. The south frigid zone is bounded by the antarctic circle, distant 23° 28′ from the south pole, which is situated in the centre of this zone.

74. AMPHISCII are the inhabitants of the torrid zone; so called, because their shadows fall north or south at different times of the year; the sun being sometimes to the south of them at noon, and at other times to the north. When the sun is vertical, or in the zenith, which happens twice in the year, the inhabitants have no shadow, and are then called ASCII, or shadowless.

75. HETEROSCII is a name given to the inhabitants of the temperate zones, because their shadows at noon fall only one way. Thus, the shadow of an inhabitant of the north temperate zone always falls to the north at noon, because the sun is then due south; and the shadow of an inhabitant of the south temperate zone falls towards the south at noon, because the sun is due north at that time.

76. PERISCII are those people who inhabit the frigid zones, so called, because their shadows, during a revolution of the earth on its axis, are directed towards every point of the compass. In the frigid zones the sun does not set during several revolutions of the earth on its axis.

77. ANTŒCI are those who live in the same degree of longitude, and in equal degrees of latitude, but the one in north and the other in south latitude. They have noon at the same time, but contrary seasons of the year; consequently, the length of the days to the one is equal to the length of the nights to the other. Those who live at the equator can have no Antœci.

78. PERIŒCI are those who live in the same latitude, but in opposite longitudes; when it is noon with the one, it is

midnight with the other; they have the same length of days, and the same seasons of the year. The inhabitants of the poles can have no Periœci.

79. ANTIPODES are those inhabitants of the earth who live diametrically opposite to each other, and consequently walk feet to feet; their latitudes, longitudes, seasons of the year, days and nights, are all contrary to each other.

80. The RIGHT ASCENSION of the sun, or of a star, is that degree of the equinoctial which rises with the sun, or star, in a right sphere, and is reckoned from the equinoctial point Aries eastward round the globe.

81. OBLIQUE ASCENSION of the sun, or of a star, is that degree of the equinoctial which rises with the sun or star, in an oblique sphere, and is likewise counted from the point Aries eastward round the globe.

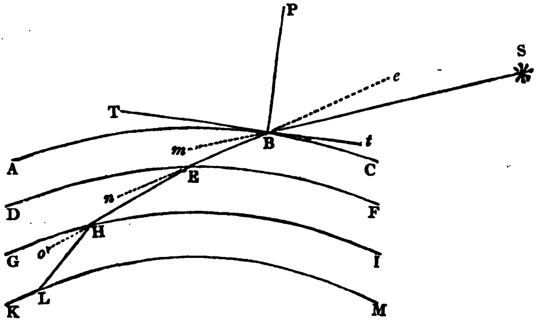
82. OBLIQUE DESCENSION of the sun, or of a star, is that degree of the equinoctial which sets with the sun or star in an oblique sphere.

83. The ASCENSIONAL or DESCENSIONAL DIFFERENCE is the difference between the right and oblique ascension, or the difference between the right and oblique descension, and, with respect to the sun, it is the time he rises before 6 in the spring and summer, or sets before 6 in the autumn and winter.

84. The CREPUSCULUM, or TWILIGHT, is that faint light which we perceive before the sun rises, and after he sets. It is produced by the rays of light being refracted in their passage through the earth's atmosphere, and reflected from the different particles thereof. The twilight is supposed to end in the evening when the sun is 18 degrees below the horizon, or when stars of the sixth magnitude (the smallest that are visible to the naked eye) begin to appear; and the twilight is said to begin in the morning, or it is *day-break*, when the sun is again within 18 degrees of the horizon. The twilight is the shortest at the equator, and longest at the poles; here the sun is near two months before he retreats 18 degrees below the horizon, or to the point where his rays are entirely withdrawn from the atmosphere; and he is only two months more before he arrives at the same parallel of latitude.

85. REFRACTION. The earth is surrounded by a body of air, called the ATMOSPHERE, through which the rays of light come to the eye from all the heavenly bodies; and since

these rays are admitted through a *vacuum*, or at least through a very *rare medium* *, and fall obliquely upon the atmosphere, which is a dense medium, they will, by the laws of optics, be refracted in lines approaching nearer to a perpendicular from the place of the observer (or nearer to the zenith) than they would be were the medium to be removed. Hence all the heavenly bodies appear higher than they really are, and the nearer they are to the horizon the greater the refraction, or difference between their apparent and true altitudes will be: at noon the refraction is the least. The sun and the moon appear of an oval figure sometimes near the horizon, by reason of refraction; for the under side being more refracted than the upper, the perpendicular diameter will be less than the horizontal one, which is not affected by refraction.



It has long been established, by experiment, that a ray of light passing from a rarer to a denser medium, is refracted towards the denser medium. Thus, if ABC be the boundary between two media, of which the lower one is the denser, then a ray of light SB, instead of pursuing its direction SBm, is deflected in the direction BE, and a star, instead of appearing at S, would appear at *e*, that is nearer to a perpendicular BP meeting a tangent Tt at the point of incidence B. Again, if DEF be a similar boundary separating the rarer medium contained between ABC and DEF from the denser medium contained between DEF and GHI, the ray of light instead of pursuing its new course BEn will be again deflected in the direction EH; and similar effects will be produced if more media and their boundaries be

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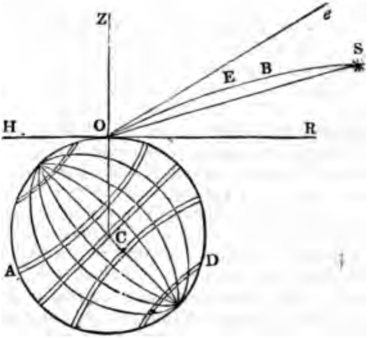
[*] Any fluid or substance through which a ray of light can penetrate, is called a medium, as air, water, oil or glass. The air near the surface of the earth is more dense than in the higher regions of the atmosphere; and beyond the atmosphere, the rays of light are supposed to meet with little or no resistance.

added. Hence, a ray of light, instead of being a continued straight line, is broken into parts BE, EH, HL, inclined to each other at the angles BEH, EHL, &c. If we suppose these media to be indefinitely increased and their boundaries to approach each other by spaces extremely small, the parts BE, EH, HL, may be considered as curvilinear, and the course of a ray, instead of being polygonal, will be a curve, concave towards the denser medium. This may be more adequately represented by the following figure.



Here the media are no longer parcelled out into different *strata* of variable density, but are considered as one medium of a density continually varying; such is the earth's atmosphere, the most dense at its surface, and decreasing towards the higher regions. A ray of light will consequently, in its passage through the atmosphere, be deflected into a curve concave towards the earth's surface, and will enter a spectator's eye in the direction of a tangent to that curve; a star will, therefore, appear in that direction.

Let O be the place of an observer, HOR his horizon, and S a star; AOD a section of the earth, formed by a vertical plane passing through the star at S and the centre (C) of the earth. Here *e* is the apparent place of the star, and S its true place; the angle *e*OR is the apparent altitude of the star, and the angle SOR its true altitude, the angle *e*OS, therefore, is the refraction. If the star were at Z, the zenith of the observer, its height would suffer no refraction.* Refraction depends upon a star's altitude and the density and temperature of the air, or upon the height of an object, and the state of the atmosphere; hence we are sometimes able to see the tops of mountains, towers, or spires of churches, which at other times are invisible, although we stand in the same place. The ancients knew nothing of refraction: the first who composed a table thereof was *Tycho Brahe.* The table now in common use was constructed from a formula by *Dr. Bradley*, being the result of numerous experiments. In the Connaissance des Tems for 1839 there is a table of refractions, calculated by Messrs. Bouvard and Arago from a formula by Laplace. (*Méchanique Celeste*, tome iv. p. 271.)

The sun's meridian altitude on the longest day decreases from the tropic of Cancer to the north pole; and in the torrid zone, when the sun is vertical there is no refraction; hence the refraction is the least in the torrid zone, and greatest at the poles. Varenius, in his Geography, speaking of the wintering of the Dutch in Nova Zembla, latitude 76° north, in the year 1596, says, they saw the sun in the year 1597 six days sooner than they would have seen him, had there been no refraction.

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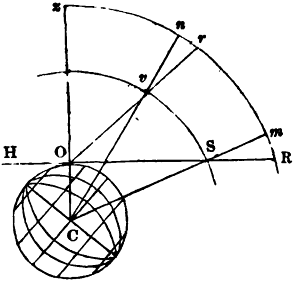
* For an illustration of the effects of the atmosphere, see Plate I. Fig. 3.

86. PARALLAX. That part of the heavens in which a planet would appear, if viewed from the surface of the earth, is called its *apparent place;* and the point in which it would be seen at the same instant from the centre of the earth is called its *true place:* the difference is the parallax. A star, on account of its great distance from the earth, has no sensible parallax.



Let C be the centre of the earth, O the place of an observer on its surface, whose sensible horizon is HOR, and zenith Z. Then if *znrm*R be a portion of a vertical circle in the heavens, and S the real place of any object in the horizon, if CS be joined and produced to *m* it will show the true place of S; the angle *m*SR or CSO is the parallax. Hence the altitudes of the celestial bodies are depressed by parallax, which is greatest at the horizon, and decreases as the altitude of the object increases; for the angle CO*v* is greater than the angle COS, consequently the angle O*v*C is less than the angle OSC. At the zenith Z the angle O*v*C vanishes, and therefore the parallax ceases.

87. ANGLE OF POSITION between two places on the terrestrial globe is an angle at the zenith of one of the places; formed by the meridian of that place, and a vertical circle passing through the other place, being measured on the horizon from the elevated pole towards the vertical circle.

THE ANGLE OF POSITION OF A STAR, is an angle formed by two great circles intersecting each other in the place of the star, the one passing through the pole of the equinoctial, the other through the pole of the ecliptic. This angle may be computed from the obliquity of the ecliptic, and the co-latitude and co-declination of the star; it is used in several astronomical calculations. *M. Lalande* has given a table of the angles of positions of stars in his Astronomy, 2d edit. vol. i. page 488.; and in the *Connaissance des Tems* for 1804, there is a table of the same kind.

88. RHUMBS are the divisions of the horizon into 32 parts, called the points of the compass. The ancients were acquainted only with the four cardinal points, and the wind was said to blow from that point to which it was nearest.[*]

A Rhumb line, geometrically speaking, is a loxodromic or spiral curve, drawn or supposed to be drawn upon the earth, so as to cut each meridian at the same angle, called the proper angle of the rhumb. If this line be continued, it will never return into itself so as to form a circle, except it happens to be due east and west, or due north and south; and it can never be a straight line upon any map, except the meridians be parallel to each other, as in Mercator's and the plane chart. Hence the difficulty of finding the *true* bearing between two places on the terrestrial globe, or on any map but those above mentioned. The bearing found by a quadrant of altitude on a globe, is only the measure of a spherical angle upon the surface of that globe, as defined by the *angle of position*, and not the real bearing or rhumb, as shown by the compass; for, by the compass, if a place A bear due east from a place B, the place B will bear due west from the place A; but this is not the case when measured with a quadrant of altitude.

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[*] Pliny's Nat. Hist. Book II. cap. 47.

89. The FIXED STARS are so called because they have usually been observed to keep the same distance with respect to each other. The stars have an apparent motion from east to west, in circles parallel to the equinoctial, arising from the revolution of the earth on its axis, from west to east: and, on account of the precession of the equinoxes, their longitudes increase about 50¼ seconds in a year; this likewise causes a variation in their declinations and right ascensions: their latitudes are also subject to a small variation.

90. The POETICAL RISING AND SETTING OF THE STARS, so called because they are taken notice of by the ancient poets, who referred the rising and setting of the stars to the sun. THUS, when a star rose with the sun, or set when the sun rose, it was said to rise and set COSMICALLY. When a star rose at sun-setting, or set with the sun, it was said to rise and set ACRONICALLY. When a star first became visible in the morning, after having been so near the sun as to be hidden by the splendour of his rays, it was said to RISE HELIACALLY; and when a star first became invisible in the evening, on account of its nearness to the sun, it was said to SET HELIACALLY.

91. A CONSTELLATION is an assemblage of stars on the surface of the celestial globe, circumscribed by the outlines of some assumed figure, as a *ram*, a *dragon*, a *bear*, &c. This division of the stars into constellations is necessary, in order to direct a person to any part of the heavens where a particular star is situated.

The following tables contain all the constellations on the BRITISH GLOBES. The ZODIACAL constellations are 12 in number, the NORTHERN constellations 35, and the SOUTHERN 49, making in the whole 96. By adding together the numbers of stars in the *first* columns of the following tables, the total will be found to be 2930; of this number there are only 19 of the first magnitude, and 422 cannot be seen at London. The largest stars are called stars of the first magnitude. Those of the sixth magnitude are the smallest that can be seen by the naked eye. The figures on the left hand of the tables show the number of stars in each constellation as given in the Royal Astronomical Society's Catalogue. Rt. Asc. denotes the right ascension, Dec. the declination of near the middle of the several constellations, for the ready finding them on the globe.

I. CONSTELLATIONS IN THE ZODIAC.

Number of Stars.	*Names of the Constellations, and of the principal Stars in each, with their Magnitudes.*	Rt. Asc.	Dec.
65.	Aries, *The Ram*, α Arietis 3,	34.	18 N.
160.	Taurus, *The Bull*, α Aldebaran 1, the Pleiades and Hyades,	62.	18 N.
83.	Gemini, *The Twins*, α^2 Castor 8, β Pollux 2,	106.	25 N.
71.	Cancer, *The Crab*, Acubene 4, or β 4,	128.	20 N.
96.	Leo, *The Lion*, α Regulus or Cor Leonis 1, Deneb 2,	155.	15 N.
123.	Virgo, *The Virgin*, α Spica Virginis 1, ε Vendemiatrix 2,	192.	3 N.
61.	Libra, *The Balance*, Zubenich Meli 2, or β Libræ	225.	15 S.
63.	Scorpio, *The Scorpion*, α Antares 1, or α Scorpii,	242.	26 S.
136.	Sagittarius, *The Archer*, σ Sagittarii 3,	285.	32 S.
81.	Capricornus, *The Goat*, α Capricorni 3,	312.	20 S.
139.	Aquarius, *The Water Bearer*, δ Scheat 3 and β 3,	332.	9 S.
123.	Pisces, *The Fishes*,	5.	10 N.

II. THE NORTHERN CONSTELLATIONS.

Number of Stars.	Names	Rt. Asc.	Dec.
25.	Andro'meda, α Alpherat 1, or β Mirach 2,	15.	35 N.
57.	Aquila, *The Eagle*, with Antinöus, α Atair 1,	291.	10 N.
36.	Auri'ga, *The Charioteer or Waggoner*, α Capella 1,	77.	42 N.
48.	Böotes, α Arcturus 1, ε Böotis 3,	216.	30 N.
13.	Camelopardalis, *The Camelopard*,	70.	68 N.
5.	Canes Venatici, and Cor Caroli, *Charles's Heart*, Asterion and Chara,	195.	40 N.
—	Caput Medusæ, *The Head of Medusa*. See Perseus,	43.	37 N.
19.	Cassiope'a, *The Lady in her Chair*, Schedar 3,	14.	60 N.
25.	Cepheus, Alderamin 3,	325.	65 N.
	Cerberus, *The Three-headed Dog*. See Hercules,	271.	18 N.
9.	Clypeum vel Scutum Sobieski, *Sobieski's Shield*,	275.	15 S.
36.	Coma Bereni'ces, *Berenice's Hair*,	188.	26 N.
13.	Corona Borealis, *The Northern Crown*, Alphacca 2,	234.	30 N.
38.	Cygnus, *The Swan*, Deneb 1,	304.	42 N.
16.	Delphi'nus, *The Dolphin*,	308.	15 N.
40.	Draco, *The Dragon*, β 2, and γ 2,	270.	66 N.
11.	Equulus, *The Little Horse*,	316.	6 N.
73.	Hercules and *Cerberus*, Ras Algethi 3,	252.	27 N.
6.	Lacerta, *The Lizard*,	336.	44 N.
11.	Leo Minor, *The Little Lion*,	151.	36 N.
8.	Lynx, *The Lynx*,	111.	50 N.

Names of the Constellations, and of the principal Stars in each, with their Magnitudes.

Number of Stars.		Rt. Asc.	Dec.
10.	Lyra, *The Harp*, *a* Vega 1	280.	35 N.
11.	Mons Mænalus[*], *The Mountain Mænalus*	225.	3 N.
6.	Musca, *The Fly*, in Ast. S. Cat. in Aries	40.	27 N.
81.	Pegasus, *The Flying Horse*, *a* Markab 2, *γ* Scheat 2	340.	15 N.
23.	Perseus, and *Caput Medusæ*, *a* Persei 2, *β* Algol 2	46.	47 N.
15.	Sagitta, *The Arrow*	295.	18 N.
57.	Serpens, *The Serpent*	234.	10 N.
—	Serpentarius, *The Serpent Bearer.* See Ophiucus	260.	0
4.	Taurus Poniatowski, *The Bull of Poniatowski*	275.	5 N.
5.	Triangulum, *The Triangle*	29.	32 N.
5.	Triangulum Minus, *The Little Triangle*	32.	29 N.
29.	Ursa Major, *The Great Bear*, Dubbe 1, Alioth 2,	153.	58 N.
10.	Ursa Minor, *The Little Bear*, *a* Polaris, or the Polar Star, or Alrukabah, 2	235.	78 N.
31.	Vulpecula et Anser, *The Fox and Goose*	300.	25 N.
10.	Tarandus, *The Rein-Deer*	45.	77 N.

To the preceding list of northern constellations, foreign mathematicians have added Le Messier, Taurus Regalis, Frederick's Ehre, *Frederick's Glory*, Tubus Herschellii Major, *Herschell's Great Telescope.*

III. THE SOUTHERN CONSTELLATIONS.

7.	Antlia Pneumatica, *The Air-Pump*	150.	35 S.
8.	Apparatus Sculptoris	5.	32 S.
3.	Apus vel Avis Indica, *The Bird of Paradise*	245.	76 S.
8.	Ara, *The Altar*	256.	54 S.
84.	Argo Navis, *The Ship Argo*, *a* Canopus 1	115.	50 S.
3.	Brandenburgium Sceptrum	67.	15 S.
4.	Cæla Sculptoris, *The Engraver's Tools*	68.	42 S.
38.	Canis Major, *The Great Dog*, *a* Sirius 1	100.	24 S.
14.	Canis Minor, *The Little Dog*, *a* Procyon 1	112.	5 N.
36.	Centaurus, *The Centaur*	195.	48 S.
106.	Cetus, *The Whale*, Mencar 2	25.	12 S.
8.	Chamæleon, *The Cameleon*	165.	78 S
2.	Circinus, *The Compasses*	220.	64 S.
13.	Columba Noachi, *Noah's Dove*	85.	35 S.
4.	Corona Australis, *The Southern Crown*	278.	40 S.
10.	Corvus, *The Crow*, Algorab 3	183.	18 S.
31.	Crater, *The Cup or Goblet*, Alkes 3	168.	15 S.
7.	Crux, *The Cross*	183.	60 S.
6.	Dorado or Xiphias, *The Sword Fish*	75.	62 S.
1.	Equuleus Pictoris, *The Painter's Easel*	80.	55 S.
83.	Erid'anus, *The River Po*, *a* Achernar 1	60.	30 S.
13.	Fornax Chemica, *The Chemist's Furnace*	42.	30 S.
12.	Grus, *The Crane*	330.	47 S.
2.	Horologium, *The Clock*	40.	57 S.

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[*] Some of the Stars in Mons Mænalus are in the Astronomical Society's Catalogue assigned to Virgo and some to Serpens.

Number of Stars.	*Names of the Constellations, and of the principal Stars in each, with their Magnitudes.*	Rt. Asc.	Dec.
54.	Hydra, *The Water Serpent*, Cor Hydræ 1	139.	10 S.
8.	Hydrus, *The Water Snake*	33.	70 S.
4.	Indus, *The Indian*	315.	55 S.
25.	Lepus, *The Hare*	80.	20 S.
25.	Lupus, *The Wolf*	230.	45 S.
1.	Microscopium, *The Microscope*	310.	37 S.
24.	Mono'ceros, *The Unicorn*	110.	2 S.
4.	Musca Australis vel Apis, *The Southern Fly*	185.	68 S.
3.	Norma vel Quadra Euclidis, *Euclid's Square*	242.	45 S.
6.	Octans	310.	80 S.
74.	Ophiu'chus, formerly called *Serpentarius*	260.	0
75.	Ori'on, α Betelgeux 1, β Rigel 1, γ Bellatrix 2	82.	0
12.	Pavo, *The Peacock*	302.	68 S.
15.	Phœnix, *A Fabulous Bird*	10.	50 S.
15.	Piscis Australis, *The Southern Fish*, α Fomalhaut 1	335.	32 S.
6.	Piscis Volans, *The Flying Fish*	127.	68 S.
11.	Pixis Nautica, *The Mariner's Compass*	132.	30 S.
—	Praxit'eles. See Cæla Sculptoris	68.	42 S.
7.	Reticulus Rhomboidalis, *The Rhomboidal Net*	60.	62 S.
12.	Robur Caroli, *Charles's Oak*	159.	60 S.
35.	Sextans, *The Sextant*	155.	0
5.	Solitarius, *An Indian Bird*	210.	21 S.
5.	Telescopium, *The Telescope*	278.	53 S.
9.	Tucan Touchan, *The American Goose*	359.	66 S.
5.	Triangulum Australe, *The Southern Triangle*	238.	65 S.

Foreign mathematicians have added to the preceding list of southern constellations, Psalterium Georgianum, *The Georgian Psaltery;* Tubus Herschellii Minor, *Herschel's Less Telescope;* Montgolfier's Balloon; The Press of Guttenberg; and The Cat.

Explanation of the different emblematical Figures delineated on the Surface of the Celestial Globe.

I. THE CONSTELLATIONS IN THE ZODIAC.

It is conjectured that the figures in the signs of the zodiac are descriptive of the seasons of the year, and that they are Chaldean or Egyptian hieroglyphics, intended to represent some remarkable occurrence in each month. Thus the spring signs were distinguished for the production of those animals which were held in the greatest esteem, viz. the sheep, the black cattle, and the goats; the latter, being the most prolific, were represented by the figure of Gemini.—When the sun enters Cancer, he discontinues his progress towards the north pole, and begins to return back towards the south pole. This retrograde motion was represented by a *Crab*, which is said to go backwards. The heat that usually follows in the next month is represented by the *Lion*, an animal remarkable for its fierceness, and which, at this season, was frequently impelled, through thirst, to leave the sandy desert and make its appearance on the banks of the Nile. The sun entered the 6th sign about the time of harvest, which season was therefore represented by a virgin or female reaper, with an ear of corn in her hand. When the sun enters *Libra*, the days and nights are equal all over the world, and seem to observe an equilibrium, like a balance.

Autumn, which produces fruits in great abundance, brings with it a variety of diseases ; this season is represented by that venomous animal the *Scorpion*, who wounds with a sting in his tail as he recedes. The fall of the leaf was the season for hunting, and the stars which marked the sun's path at this time were represented by a huntsman, or *archer*, with his arrows and weapons of destruction.

The *Goat*, which delights in climbing and ascending some mountain or precipice, is the emblem of the winter solstice, when the sun begins to ascend from the southern tropic, and gradually to increase in height for the ensuing half year.

Aquarius, or the Water-bearer, is represented by the figure of a man pouring out water from an urn, an emblem of the dreary and uncomfortable season of winter.

The last of the zodiacal constellations was *Pisces*, or a couple of fishes tied back to back, representing the fishing season. The severity of the winter is over, the flocks do not afford sustenance, but the seas and rivers are open, and abound with fish.

The Chaldeans and Egyptians were the original inventors of astronomy; they registered the events in their history, and the mysteries of their religion, among the stars by emblematical figures. The Greeks displaced many of the Chaldean constellations, and placed such images as had reference to their own history in their room. The same method was followed by the Romans; hence the accounts given of the signs of the zodiac, and of the constellations, are contradictory and involved in fable.

II. THE NORTHERN CONSTELLATIONS.

Andro'meda is represented on the celestial globe by the figure of a woman almost naked, having her arms extended, and chained by the wrist of her right arm to a rock. She was the daughter of Cepheus, king of Æthiopia, who, in order to preserve his kingdom, was obliged to tie her naked to a rock near Joppa, now Jaffa, in Syria, to be devoured by a sea-monster ; but she was rescued by Perseus, in his return from the conquest of the Gorgons, who turned the monster into a rock by shewing it the head of Medusa. Andromeda was made a constellation after her death by Minerva.

Antinöus was a youth of Bithynia, in Asia Minor, a great favourite of the emperor Adrian, who erected a temple to his memory, and placed him among the constellations. — Antinöus is generally reckoned a part of the constellation Aquila.

Aquila is supposed to have been Merops, a king of the island of Cos, one of the Cyclades; who, according to Ovid, was changed into an eagle, and placed among the constellations.

Asterion et Chara, *vel* **Canes Venatici**, the Two Greyhounds, held in a string by Boötes: they were formed by Hevelius out of the *Stellæ Informes* of the ancient catalogues.

Auri'ga is represented on the celestial globe by the figure of a man in a kneeling or sitting posture, with a goat and her kids in his left hand, and a bridle in his right. The Greeks give various accounts of this constellation; some suppose it to be Erichthonius, the fourth king of Athens, and son of Vulcan and Minerva; he was very deformed, and his legs resembled the tails of serpents; he is said to have invented chariots, and the manner of harnessing horses to draw them. Others say that Auriga is Myrtilus, a son of Mercury and Phaëtusa; he was charioteer to Œnomaus, king of Pisa, in Elis, and so experienced in riding and the management of horses, that he rendered those of Œnomaus the swiftest in all Greece; his infidelity to his master proved at last fatal to him, but being a son of Mercury, he was made a constellation after his death. But as neither of these fables seems to account for the goat and her kids, it has been supposed that they refer to Amalthæa, daughter of Melissus, king of Crete, who, in conjunction with her sister Melissa, fed Jupiter with goats' milk; it is moreover said that Amalthæa was a goat called Olenia, from its residence at Olenus, a town of Peloponnesus.

Boötes is supposed to be Arcas, the son of Jupiter and Calisto; Juno, who was jealous of Jupiter, changed Calisto into a bear; she was near being killed by her son Arcas in hunting. Jupiter, to prevent farther injury from the huntsmen, made Calisto a constellation of heaven, and on the death of Arcas, conferred the same honour on him. Boötes is represented as a man in a walking posture, grasping in his left hand a club, and having his right hand extended upwards, holding the cord of the two dogs, Asterion and Chara, which seem to be barking at the Great Bear; hence Boötes is sometimes called the bear-driver, and the office assigned him is to drive the two bears round about the pole.

Camelopardalis was formed by Hevelius. The camelopard is remarkably tame and tractable; its habits resemble those of the camel, and its body is variegated with spots like the leopard. This animal is to be found in Ethiopia and other parts of Africa; its neck is about seven feet long, its fore and hind legs from the hoof to the second joint, are nearly of the same length; but from the second joint of the legs to the body, the fore legs are so long in comparison with the hind ones, that the body seems to slope like the roof of a house.

Cassiope'a was the wife of Cepheus, and mother of Andromeda. *See these constellations, as also Cetus.*

Cepheus was a king of Æthiopia, and the father of Andromeda by Cassiopea; Cepheus was one of the Argonauts, who went with Jason to Colchis to fetch the golden fleece.

Cerberus was a dog belonging to Pluto, the god of the infernal regions; this dog had fifty heads, according to Hesiod; and three, according to other mythologists: he was stationed at the entrance of the infernal regions, as a watchful keeper, to prevent the living from entering, and the dead from escaping from their confinement. The last and most dangerous exploit of Hercules was to drag Cerberus from the infernal regions, and bring him before Eurystheus, king of Argos.

Coma Bereni'ces is composed of the unformed stars, between the Lion's tail and Boötes. Berenice was the wife of Evergetes, a surname signifying benefactor; when he went on a dangerous expedition, she vowed to dedicate her hair to the goddess Venus, if he returned in safety. Some time after the victorious return of Evergetes, the locks which were in the temple of Venus disappeared; and Conon, an astronomer, publicly reported that Jupiter had carried them away, and made them a constellation.

Cor Caroli, or Charles's Heart, in the neck of Chara, the southernmost of the two dogs held in a string by Boötes, was so denominated by Sir Charles Scarborough, physician to king Charles II., in honour of king Charles I.

Coro'na Borea'lis is a beautiful crown given by Bacchus, the son of Jupiter, to Ariadne, the daughter of Minos, second king of Crete. Bacchus is said to have married Ariadne after she was basely deserted by Theseus, king of Athens, and after her death the crown which Bacchus had given her was made a constellation.

Cygnus is fabled by the Greeks to be the swan under the form of which Jupiter deceived Leda, or Nemesis, the wife of Tyndarus, king of Laconia. Leda was the mother of Pollux and Helena, the most beautiful woman of the age; and also of Castor and Clytemnestra. The two former were deemed the offspring of Jupiter, and the others claimed Tyndarus as their father.

Delphi'nus, the Dolphin, was placed among the constellations by Neptune; because, by means of a dolphin, Amphitrite became the wife of Neptune, though she had made a vow of perpetual celibacy.

Draco. The Greeks give various accounts of this constellation: by some it is represented as the watchful dragon which guarded the golden apples in the garden of the Hesperides, near mount Atlas in Africa, and was slain by Hercules: Juno, who presented these apples to Jupiter on the day of their nuptials, took Draco up to heaven, and made a constellation of it, as a reward for its faithful services: others maintain that in a war with the giants, this dragon was brought into combat, and opposed to Minerva, who seized it in her hands, and threw it, twisted as it was, into the heavens round the axis of the earth, before it had time to unwind its contortions.

Equulus, the Little Horse, or *Equi Sectio*, the Horse's Head, is supposed to be the brother of Pegasus.

Hercules is represented on the celestial globe holding a club in his right hand, the three-headed dog Cerberus in his left, and the skin of the Nemæan lion thrown over his shoulders. Hercules was the son of Jupiter and Alcmena, and reckoned the most famous hero in antiquity.

Lacerta, the Lizard, was added by Hevelius to the old constellations.

Leo Minor was formed out of the *Stellæ Informes*, or unformed stars of the ancients, and placed above **Leo** the zodiacal constellation. According to the Greek fables, **Leo** was the celebrated Nemæan lion which had dropped from the moon; but being slain by Hercules, was elevated to the heavens by Jupiter, in commemoration of the dreadful conflict, and in honour of that hero. But this constellation was amongst the Egyptian hieroglyphics, long before the invention of the fables of Hercules. *See the Zodiacal Constellations*, p. 24. Nemæa was a town of Argolis in Peloponnesus, and was infested by a lion which Hercules slew, and clothed himself in the skin; games were instituted to commemorate this great event.

The **Lynx** was composed by Hevelius out of the unformed stars of the ancients, between Auriga and Ursa Major.

Lyra, the Lyre or harp, is included in Vultur Cadens. This constellation was at first a tortoise, afterwards a lyre, because the strings of the lyre were originally fixed to the shell of a tortoise: it is asserted that this is the lyre which Apollo or Mercury gave to Orpheus, and with which he descended into the infernal regions, in search of his wife Eurydice. Orpheus after death received divine honours, the Muses gave an honourable burial to his remains, and his lyre became one of the constellations.

Mons Mænalus. The mountain Mænalus in Arcadia was sacred to the god Pan, and frequented by shepherds; it received its name from Mænalus, a son of Lycaon, king of Arcadia.

Pegasus, the Winged Horse, according to the Greeks, sprang from the blood of the Gorgon Medusa, after Perseus, a son of Jupiter, had cut off her head. Pegasus fixed his residence on mount Helicon in Bœotia, where, by striking the earth with his foot, he produced a fountain called Hippocrene. He became the favourite of the Muses; and being afterwards tamed by Neptune, or Minerva, he was given to Bellerophon to conquer the Chimæra, a hideous monster that continually vomited flames; the fore-parts of its body were those of a lion, the middle was that of a goat, and the hinder-parts were those of a dragon; it had three heads, viz. that of a lion, a goat, and a dragon. After the destruction of this monster, Bellerophon attempted to fly to heaven upon Pegasus, but Jupiter sent an insect which stung the horse, so that he threw down the rider. Bellerophon fell to the earth, and Pegasus continued his flight up to heaven, and was placed by Jupiter among the constellations.

Perseus is represented on the globe with a sword in his right hand, the head of Medusa in his left, and wings at his ancles. Perseus was the son of Jupiter and Danaë. Pluto, the god of the infernal regions, lent him his helmet, which had the power of rendering its bearer invisible; Minerva, the goddess of wisdom, furnished him with her buckler, which was resplendent as glass; and he received from Mercury wings, and a dagger or sword: thus equipped, he cut off the head of Medusa, and from the blood which dropped from it in his passage through the air, sprang an incalculable number of serpents, which ever after infested the sandy deserts of Libya. Medusa was one of the three Gorgons who had the power to turn into stone all those on whom they fixed their eyes: Medusa was the only one subject to mortality: she was celebrated for the beauty of her locks; but having violated the sanctity of the temple of Minerva, that goddess changed her locks into serpents. *See the constellation Andromeda.*

Sagitta, the Arrow. The Greeks say that this constellation owes its origin to one of the arrows of Hercules, with which he killed the eagle or vulture that perpetually gnawed the liver of Prometheus, who was tied to a rock on Mount Caucasus, by order of Jupiter.

Scutum Sobieski was so named by Hevelius, in honour of John Sobieski king of Poland. Hevelius was a celebrated astronomer, born at Dantzic: his catalogue of fixed stars was entitled *Firmamentum Sobieskianum*, and dedicated to the king of Poland.

Serpens is also called *Serpens Ophiuchi*, being grasped by the hands of *Ophiuchus*.

Serpentarius, *Ophiuchus*, or *Æsculapius*, is represented with a large beard, and holding in his two hands a serpent. The serpent was the symbol of medicine, and of the gods who presided over it, Apollo and Æsculapius.

Taurus Poniatowski was so called in honour of Count Poniatowski, a Polish officer of extraordinary merit, who saved the life of Charles XII. of Sweden, at the battle of Pultowa, a town near the Dnieper, about 150 miles south-east of Kiov; and a second time at the island of Rugen, near the mouth of the river Oder.

Triangulum. A triangle is a well known figure in geometry; it was placed in the heavens in honour of the most fertile part of Egypt, being called the delta of the Nile, from its resemblance to the Greek letter of that name Δ. The invention of geometry is usually ascribed to the Egyptians, and it is asserted that the annual inundations of the Nile, which swept away the bounds and land-marks of estates, gave occasion to it, by obliging the Egyptians to consider the figure and quantity belonging to the several proprietors.

Ursa Major is said to be Calisto, an attendant of Diana, the goddess of hunting. Calisto was changed into a bear by Juno. *See the constellation Boötes.* It is farther stated that the ancients represented Ursa Major and Ursa Minor, each under the form of a waggon, drawn by a team of horses. Ursa Major is well known to the country people at this day, by the title of *Charles's Wain*, or waggon: in some places it is called the plough. There are two remarkable stars in Ursa Major, considered as the hindmost in the square of the wain, called the pointers, because an imaginary line drawn through these stars, and extended upwards to four times the distance of the space between them, will pass close to the pole-star in the tail of the Little Bear.

Vulpecula et Anser, the Fox and the Goose: this constellation was made by Hevelius out of the unformed stars of the ancients.

III. THE SOUTHERN CONSTELLATIONS.

Ara is supposed to be the altar on which the gods swore before their combat with the giants.

Argo Navis is said to be the ship Argo, which carried Jason and the Argonauts to Colchis, to fetch the golden fleece.

Canis Major, the Great Dog, according to the Greek fables is one of Orion's hounds (*See Canis Minor*); but the Egyptians, who carefully watched the rising of this constellation, and by it judged of the swelling of the Nile, called the bright star Sirius the sentinel and watch of the year; and according to their hieroglyphical manner of writing represented it under the figure of a dog. The Egyptians called the Nile *Siris*, and hence is derived the name of their deity *Osiris*.

Canis Minor, the Little Dog, according to the Greek fables, is one of Orion's hounds; but the Egyptians were most probably the inventors of this constellation; and as it rises before the dog-star, which at a particular season was so much dreaded, it is properly represented as a little watchful creature, giving notice of the other's approach; hence the Latins have called it Antecanis, the star before the dog.

Centaurus. The Centauri were a people of Thessaly, half men and half horses. The Thessalians were celebrated for their skill in taming horses, and their appearance on horseback was so uncommon a sight to the neighbouring states, that at a distance they imagined the man and horse to be one animal: when the Spaniards landed in America, and appeared on horseback, the Mexicans had the same ideas. This constellation is by some supposed to represent Chiron the Centaur, tutor of Achilles, Æsculapius, and Hercules; but as Sagittarius is likewise a Centaur, others have contended that Chiron is represented by Sagittarius.

Cetus, the Whale, is pretended by the Greeks to be the sea-monster which Neptune, brother to Juno, sent to devour Andromeda; because her mother, Cassiopea, had boasted herself to be fairer than Juno and the Nereides.

Corvus, the Crow, was according to the Greek fables made a constellation by Apollo: this god being jealous of Coronis, (the daughter of Phlegyas and mother of Æsculapius,) sent a crow to watch her behaviour; the bird, perched on a tree, perceived her criminal partiality to Ischys, the Thessalian, and acquainted Apollo with her conduct.

Crux, **Crusero**, or **Crosier**. There are four stars in this constellation, forming a cross, by which mariners sailing in the southern hemisphere readily find the situation of the Antarctic pole.

Erid'anus, the river Po, called by Virgil the king of rivers, was placed in the heavens for receiving Phaëton, whom Jupiter struck with thunderbolts when the earth was threatened with a general conflagration, through the ignorance of Phaëton, who had presumed to be able to guide the chariot of the sun. The Po is sometimes called Orion's river.

Hydra is the Water Serpent, which, according to poetic fable, infested the lake Lerna, in Peloponnesus: this monster had a great number of heads; and as soon as one was cut off, another grew in its stead: it was killed by Hercules. The general opinion is, that this Hydra was only a multitude of serpents which infested the marshes of Lerna.

Lepus, the Hare, according to the Greek fables, was placed near Orion, as being one of the animals which he hunted.

Microscopium, the Microscope, is an optical instrument composed of lenses or mirrors, so arranged as to render very minute objects clear and distinct.

Mono'ceros, the Unicorn, was added by Hevelius, and composed of stars which the ancients had not comprised within the outlines of the other constellations.

Ori'on is represented on the globe by the figure of a man with a sword in his belt, a club in his right hand, and the skin of a lion in his left; he is said by some authors to be the son of Neptune and Euryale, a famous huntress; he possessed the disposition of his mother, became the greatest hunter in the world, and boasted that there was not any animal on the earth which he could not conquer. Others say, that Jupiter, Neptune, and Mercury, as they travelled over Bœotia, met with great hospitality from Hyrieus, a peasant of the country, who was ignorant of their dignity and character. When Hyrieus had discovered that they were gods, he welcomed them by the voluntary sacrifice of an ox. Pleased with his piety, the gods promised to grant him whatever he required, and the old man, who had lately lost his wife, and to whom he made a promise never to marry again, desired them, that as he was childless, they would give him a son without obliging him to break his promise. The gods consented, and Orion was produced from the hide of the ox.

Piscis Australis, the Southern Fish, is supposed by the Greeks to be

Venus, who transformed herself into a fish, to escape from the terrible giant Typhon.

ROBUR CAROLI, or Charles's Oak, was so called by Dr. Halley, in memory of the tree in which Charles II. saved himself from his pursuers after the battle of Worcester. Dr. Halley went to St. Helena, in the year 1676, to take a catalogue of such stars as do not rise above the horizon of London.

SEXTANS, the Sextant, a mathematical instrument well known to mariners was formed by Hevelius from the *Stellæ Informes* of the ancients.

92. GALAXY, VIA LACTEA, or *Milky-way*, is a whitish luminous tract which seems to encompass the heavens, like a girdle, of a considerable though unequal breadth, varying from about 4 to 20 degrees. It is composed of an infinite number of small stars, which by their joint light occasion that confused whiteness which we perceive in a clear night when the moon does not shine very brightly. The milky-way may be traced on the celestial globe, beginning at Cygnus, through Cepheus, Cassiopea, Perseus, Auriga, Orion's club, the feet of Gemini, part of Monoceros, Argo Navis, Robur Caroli, Crux, the feet of the Centaur, Circinus, Quadra Euclidis, and Ara; here it is divided into two parts; the eastern branch passes through the tail of Scorpio, the bow of Sagittarius, Scutum Sobieski, the feet of Antinöus, Aquila, Sagitta, and Vulpecula; the western branch passes through the upper part of the tail of Scorpio, the right side of Serpentarius, Taurus Poniatowski, the Goose, and the neck of Cygnus, and meets the aforesaid branch in the body of Cygnus.

93. NEBULOUS, or *cloudy*, is a term applied to certain fixed stars, smaller than those of the 6th magnitude, which only show a dim hazy light, like little specks or clouds. (NEBULÆ.) In Præsepe in the breast of Cancer are reckoned 36 little stars; F. le Comte adds, that there are 40 such stars in the Pleiades, and 2500 in the whole Constellation of Orion. It may be further remarked, that the Milky-way is a continued assemblage of Nebulæ.

94. BAYER'S CHARACTERS. John Bayer of Augsburg in Swabia, published in 1603 an excellent work, entitled *Uranometria*, being a complete atlas of all the constellations, with the useful invention of denoting the stars in every constellation by the letters of the Greek and Roman Alphabets: setting the first Greek letter α to the principal star in each constellation, β to the second in magnitude, γ to

the third, and so on, and when the Greek alphabet was finished, he began with *a*, *b*, *c*, &c. of the Roman. This useful method of describing the stars has been adopted by all succeeding astronomers, who have farther enlarged it by adding the numbers 1, 2, 3, &c. in the same regular succession, when any constellation contains more stars than can be marked by the two alphabets. When several neighbouring stars in the same constellation are marked with the same Greek letter, they are distinguished by figures placed above the letters, as δ^1 Tauri, δ^2 Tauri, ω^1 Cygni, ω^2 Cygni, &c. The most complete catalogue of the fixed stars is published by the Royal Astronomical Society.

As the Greek letters so frequently occur in catalogues of the stars and on the celestial globes, the Greek alphabet is here introduced for the use of those who are unacquainted with the letters. The capitals are seldom used in the catalogues of stars, but are here given for the sake of regularity.

THE GREEK ALPHABET.

		Name.	*Sound.*			*Name.*	*Sound.*
Α	α	Alpha	a	Ν	ν	Nu	n
Β	β ϐ	Beta	b	Ξ	ξ	Xi	x
Γ	γ ʃ	Gamma	g	Ο	ο	Omicron	o *short*
Δ	δ	Delta	d	Π	π ϖ	Pi	p
Ε	ε	Epsilon	e *short*	Ρ	ρ	Rhc	r
Ζ	ζ ζ	Zeta	z	Σ	Ϲ σ ς	Sigma	s
Η	η	Eta	e *long*	Τ	τ ⌉	Tau	t
Θ	ϑ θ	Theta	th	Υ	υ	Upsilon	u
Ι	ι	Iota	i	Φ	φ	Phi	ph
Κ	κ	Kappa	k	Χ	χ	Chi	ch
Λ	λ	Lambda	l	Ψ	ψ	Psi	ps
Μ	μ	Mu	m	Ω	ω	Omega	o *long.*

95. Planets are erratic opaque bodies resembling our earth; and, having no light of their own, they shine only by reflecting the light of the sun. They are divided into three classes, viz. Primary Planets, Minor Primary Planets, and Secondary Planets, commonly called Satellites or Moons.

96. The PRIMARY PLANETS are those which revolve round the sun as a centre: they are eight in number: their order in the system, and the names and characters by which they are expressed being as follows: Mercury ☿, Venus ♀, Earth ⊖, Mars ♂, Jupiter ♃, Saturn ♄, Uranus ♅, called also the *Georgium Sidus* or *Herschel*, and Neptune ♆.

97. The MINOR PRIMARY PLANETS are seven in number: they revolve round the sun as a centre, between the orbits of

Mars and Jupiter, but are distinguished from the primary planets by their diminutive size, and by the form and position of their orbits. Their names are Vesta ⚶, Juno ⚵, Ceres ⚳, Pallas ⚴, Astræa, Iris, and Hebe.*

Superior and inferior, or exterior and interior, are relative terms applied to the primary and minor primary planets; those being called superior or exterior, which are farther from the sun; and those inferior or interior, which are nearer to him: thus, in respect of our earth, Mercury and Venus are inferior planets, and the rest are superior. Mercury being the nearest planet to the sun, and Neptune the most remote from him, may be considered, the former as the inferior planet of the system, and the latter the superior.

98. The Secondary Planets are those bodies which revolve round their respective primaries as their centre of motion, in the same manner as the primary planets circulate round the sun. The number of satellites at present known is eighteen; viz. the Moon ☽, which attends on our earth, four belonging to Jupiter, seven to Saturn, six to Uranus, and one to Neptune.

99. The Orbit of a planet is the imaginary path it describes round the sun.

100. Nodes are the two opposite points where the orbit of a planet seems to intersect the ecliptic. That where the planet appears to ascend from the south to the north side of the ecliptic is called the ascending or north node, and is marked thus ☊; and the opposite point where the planet appears to descend from the north to the south is called the descending or south node, and is marked ☋.

101. Aspect of the stars or planets is their situation with respect to each other. There are five aspects; viz. ☌ *Conjunction*, when they are in the same sign and degree; ⚹ *Sextile*, when they are two signs, or a sixth part of a circle, distant; □ *Quartile*, when they are three signs, or a fourth part of a circle, from each other; △ *Trine*, when they are four signs, or a third part of a circle, from each other; ☍ *Opposition*, when they are six signs, or half a circle from each other.

The conjunction and opposition (particularly of the moon) are called the *Syzygies*, and the quartile aspect, the *Quadratures*.

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* The characters of the three last have not been fixed.

102. DIRECT. A planet's motion is said to be direct when it appears (to a spectator on the earth) to go forward in the zodiac, according to the order of the signs.

103. STATIONARY. A planet is said to be stationary when (to an observer on the earth) it appears for some time in the same point of the heavens.

104. RETROGRADE. A planet is said to be retrograde when it apparently goes backward, or contrary to the order of the signs.

105. DIGIT, the twelfth part of the sun or moon's apparent diameter.

106. DISC, the face of the sun or moon such as they appear to a spectator on the earth; for though the sun and moon be really spherical bodies, they appear to be circular planes.

107. GEOCENTRIC latitudes and longitudes of the planets are their latitudes and longitudes, as seen from the earth.

108. HELIOCENTRIC latitudes and longitudes of the planets are their latitudes and longitudes, as they would appear to a spectator situated in the sun.

109. APOGEE, or Apogæum, is that point in the orbit of a planet, the moon, &c. which is farthest from the earth.

110. PERIGEE, or Perigæum, is that point in the orbit of a planet, the moon, &c. which is nearest to the earth.

111. APHELION, or Aphelium, is that point in the orbit of the earth, or of any other planet, which is farthest from the sun. This point is called the higher Apsis.

112. PERIHELION, or Perihelium, is that point in the orbit of the earth, or of any other planet, which is nearest to the sun. This point is called the lower Apsis.

113. LINE OF THE APSIDES is a straight line joining the higher and lower apsis of a planet; viz. a line joining the Aphelium and Perihelium.

114. ECCENTRICITY of the orbit of any planet is the distance between the sun and the centre of the planet's orbit.

115. OCCULTATION is the obscuration or hiding from our sight any star or planet, by the interposition of the body of the moon, or of some other planet.

116. TRANSIT is the apparent passage of any planet over the face of the sun, or over the face of another planet. Mercury and Venus, in their transits over the sun's disc, appear like dark specks.

117. ECLIPSE OF THE SUN is an occultation of part of the face of the sun, occasioned by an interposition of the moon

between the earth and the sun; consequently all eclipses of the sun happen at the time of the new moon.

118. **ECLIPSE OF THE MOON** is a privation of the light of the moon, occasioned by an interposition of the earth between the sun and the moon; consequently all eclipses of the moon happen at full moon.

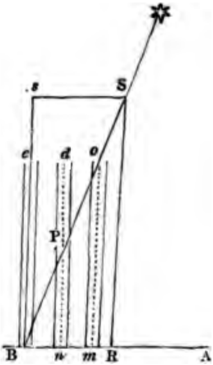
119. **ELONGATION** of a planet is the angle formed by two lines drawn from the earth, the one to the sun, and the other to the planet.*

120. **DIURNAL ARC** is the arc described by the sun, moon, or stars, from their rising to their setting. — The sun's semi-diurnal arc is the arc described in half the length of the day.

121. **NOCTURNAL ARC** is the arc described by the sun, moon, or stars, from their setting to their rising.

122. **ABERRATION** is an apparent motion of the celestial bodies, occasioned by the earth's annual motion in its orbit, combined with the progressive motion of light.

To illustrate this definition. — If light be supposed to have a progressive motion, the position of the telescope through which a star is viewed must be different from that which it would have been, if light had been instantaneous, and therefore the situation of a star *measured* in the heavens, will be different from its *true* situation. Let ✶ represent the situation of a fixed star, A B the direction of the earth's motion, ✶ B the direction of a particle of light, entering the axis *mo* of a telescope at *o*, and moving through *o* B whilst the earth moves from *m* to B, then if the telescope be kept parallel to itself, the light will descend in the axis.



For, let the axis *nd*, B*e* continue parallel to *mo*, then if each motion be considered as uniform, (that of the spectator, occasioned by the earth's rotation, being disregarded, because it is so small as to produce no effect,) the spaces described in the same time will retain the same ratio; now *m*B and *o*B being described in the same time, and because *m*B : *o*B : : *mn* : *o*P, it follows that *mn* and *o*P are also described in the same portion of time, and therefore when the telescope is in the situation *nd* the particle of light will be at F in the telescope, and this being the case in every moment of its descent, the situation of the star, measured by the telescope at B, is *s*, and the angle ✱ B*s* is the *aberration*. Hence it appears, that if we take BS : BR : : the velocity of light : the velocity of the earth, and complete the parallelogram BRS*s*, the *aberration* will be equal to the angle BSR or SB*s*; S will be the *true* place of the star, and *s* the place measured by the instrument, or its situation as seen by the naked eye.

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* This and some of the preceding definitions are given to illustrate the 38th and 39th pages of White's Ephemeris, called *Speculum Phænomenorum*. The words *elong. max.* signify the greatest elongation of a planet. In *Plate* II. *Fig.* 2. E represents the earth, V Venus, and S the sun. The elongation is the angle V E S, measured by the arc V S.

123. CENTRIPETAL* FORCE is that force with which a moving body is perpetually urged towards a centre, and made to revolve in a curve instead of proceeding in a straight line, for all motion is naturally rectilinear. Centripetal force, attraction and gravitation, are terms of the same import.

124. CENTRIFUGAL† FORCE is that force with which a body revolving about a centre, or about another body, endeavours to recede from that centre, or body. — There are two kinds of centrifugal force, viz. that which is given to bodies moving round another body as a centre, usually called the PROJECTILE or TANGENTIAL FORCE, and that which bodies acquire by revolving upon their own axes. Thus, for example, the annual orbit of the earth round the sun is described by the action of the centripetal and projectile forces : — And the diurnal rotation of the earth on its axis gives to all its parts a centrifugal force proportional to its velocity.

Sir Isaac Newton has demonstrated, (Princip. Prop. XIX. Book III.) that the "centrifugal force of bodies at the equator, is to the centrifugal force with which bodies recede from the earth, in the latitude of Paris, in the duplicate ratio of the radius, to the co-sine of the latitude. — And that the centripetal power in the latitude of Paris, is to the centrifugal force at the equator as 289 is to 1."

GEOGRAPHICAL THEOREMS.

1. The latitude of any place in the northern hemisphere is equal to the elevation of the polar star (nearly) above the horizon; and the elevation of the equator above the horizon is equal to the complement of the latitude, or what the latitude wants of 90 degrees.

2. All places lying under the equinoctial, or on the equator, have no latitude, and all places situated on the first meridian have no longitude; consequently that particular point on the

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* This word is derived from *centrum*, the centre, and *peto*, I seek.

† *Centrum*, the centre; *fugio*, I fly from.

globe where the first meridian intersects the equator, has neither latitude nor longitude.

3. The latitudes of places increase as their distances from the equator increase. The greatest latitude a place can have is 90 degrees.

4. The longitudes of places increase as their distances from the first meridian increase, reckoned on the equator. The greatest longitude a place can have is 180 degrees, being half the circumference of the globe at that place; hence no two places can be at a greater distance from each other than 180 degrees.

5. The sensible horizon varies as we travel from one place to another, and its semi-diameter is affected by refraction.

6. All countries upon the face of the earth, in respect to time, equally enjoy the light of the sun, and are equally deprived of the benefit of it; that is, every inhabitant of the earth has the sun above his horizon for six months, and below his horizon for the same length of time.*

7. In all places of the earth, except exactly under the poles, the days and nights are of an equal length (viz. 12 hours each), when the sun has no declination, that is, on the 21st of March, and on the 23d of September.

8. In all places situated on the equator, the days and nights are always equal, notwithstanding the alteration of the sun's declination from north to south, or from south to north.

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* This, though nearly true, is not accurately so. The refraction in high latitudes is very considerable (see definition 85th), and near the poles the sun will be seen for several days before he comes above the horizon; and he will, for the same reason, be seen for several days after he has descended below the horizon. — The inhabitants of the poles (if any) enjoy a very large degree of twilight, the sun being nearly two months before he retreats 18 degrees below the horizon, or to the point where his rays are first admitted into the atmosphere, and he is only two months more before he arrives at the same parallel of latitude: and particularly near the north-pole, the light of the moon is greatly increased by the reflection of the snow, and the brightness of the Aurora Borealis; the sun is likewise about *seven days* longer in passing through the northern than through the southern signs; that is, from the vernal equinox, which happens on the 21st of March, to the autumnal equinox, which falls on the 23rd of September, being the summer half-year to the inhabitants of north latitude, is 186 days, the winter half-year is therefore only 179 days. The inhabitants near the north-pole have consequently more light in the course of a year than any other inhabitants on the surface of the globe.

9. In all places, except those upon the equator, or at the two poles, the days and nights are never equal, but when the sun enters the signs of *Aries* and *Libra*, viz. on the 21st of March, and on the 23d of September.

10. In all places lying under the same parallel of latitude, the days and nights, at any particular time, are always equal to each other.

11. The increase of the longest days from the equator northward or southward, does not bear any certain ratio to the increase of latitude; if the longest days increase equally, the latitudes increase unequally. This is evident from the table of climates.

12. To all places in the torrid zone the morning and evening twilight are the shortest: to all places in the frigid zones the longest; and to all places in the temperate zones, a medium between the other two.

13. To all places lying within the torrid zone the sun is vertical twice a year: to those under each tropic once, but to those in the temperate and frigid zones, it is never vertical.

14. At all places in the frigid zones the sun appears every year without setting for a certain number of days, and disappears for nearly the same length of time; and the nearer the place is to the pole, the longer the sun continues without setting; viz. the length of the longest days and nights increase the nearer the place is to the pole.

15. Between the end of the longest day and the beginning of the longest night, in the frigid zone, and between the end of the longest night, and the beginning of the longest day, the sun rises and sets as at other places on the earth.

16. At all places situated under the arctic or antarctic circles, the sun when he has 23° 28′ declination, appears for 24 hours without setting; but rises and sets at all other times of the year.

17. At all places between the equator and the north-pole the longest day and the shortest night are when the sun has (23° 28′) the greatest north declination; and the shortest day and longest night are when the sun has the greatest south declination.

18. At all places between the equator and the south-pole the longest day and the shortest night are when the sun has (23° 28′) the greatest south declination; and the shortest

day and longest night are when the sun has the greatest north declination.

19. At all places situated on the equator the shadow at noon of an object, placed perpendicular to the horizon, falls towards the north for one half of the year, and towards the south the other half.

20. The nearer any place is to the torrid zone, the shorter the meridian shadow of an object will be. When the sun's altitude is 45 degrees, the shadow of any perpendicular object is equal to its height.

21. The farther any place (situated in the temperate or torrid zones) is from the equator, the greater the rising and setting amplitude of the sun will be.

22. All places situated under the same meridian, so far as the globe is enlightened, have noon at the same time.

23. If a ship set out from any port, and sail round the earth eastward to the same port again, the people in that ship, in reckoning their time, will gain one complete day at their return, or count one day more than those who reside at the same port. If they sail westward they will lose one day, or reckon one day less. To illustrate this, suppose the person who travels westward should keep pace with the sun, it is evident he would have continual day, or it would be the *same* day to him during his tour round the earth; but the people who remained at the place whence he departed, have had night in the same time, consequently they reckon a day more than he does.

24. Hence, if two ships should set out at the same time from any port, and sail round the globe, the one eastward and the other westward, so as to meet at the same port on any day whatever, they will differ two days in reckoning their time at their return. If they sail twice round the earth they will differ four days; if thrice, six, &c.

25. But if two ships should set out at the same time from any port and sail round the globe, northward or southward, so as to meet at the same port on any day whatever, they will not differ a minute in reckoning their time, nor from those who reside at the port.

CHAPTER II.

Of the General Properties of Matter and the Laws of Motion.

1. MATTER may be defined to be that which occupies space and makes an impression on our senses. It is known to us only by its properties.

2. The PROPERTIES OF MATTER which are considered essential to our knowledge of its existence, are extension and impenetrability. There are other properties which are not essential, such as divisibility, porosity, and elasticity. Even that important property, known under the name of Attraction or GRAVITATION, is not absolutely *necessary* to the existence of matter, although no matter has been found destitute of gravity.

3. EXTENSION. It is by this property that matter occupies space, and it is familiarly known to us under the name of bulk or volume. The figure, shape, or external outline of a body, is therefore determined by this property of extension. In speaking of solids, their extension is comprised in the three dimensions of length, breadth and thickness; while the extension of liquid and gaseous bodies, such as water or air, is determined by the capacity of the vessel which contains them.

4. SOLIDITY is not a property, but rather a condition of matter, depending on the force of attraction among the particles. Thus water, which is a body commonly known to us as a *liquid*, may in certain cases assume the form of a *solid*, as ice, or of a *gas*, as steam; while, on the other hand, carbonic acid or fixed air, which commonly exists in the form of a *gas*, may be made by chemical and mechanical processes to assume both the *liquid* and *solid* conditions.

5. IMPENETRABILITY. This is a property of matter by which a body, whether solid, liquid, or gaseous, excludes all other bodies from the space which it occupies. It is self-evident, with regard to solids, for it is impossible to thrust one solid body into the space occupied by another: but it is not so obvious with respect to liquids and gases, owing to the great mobility of their particles, in consequence of which they become displaced by the slightest disturbing causes.

When the hand is plunged into water, the particles of water are merely separated and rise over each other; they are not penetrated but displaced. If a quantity of air be confined in a bladder so that it cannot escape, the property of impenetrability will be manifested; for, on compressing the bladder, it will be found impossible to force a solid body into the space occupied by the air. The air is condensed or reduced to a smaller bulk, *i. e.* its particles are brought closer together under pressure, by reason of another property, Compressibility, which exists to a remarkable degree in gases; but the particles of air resist penetration just as much as those of gold and silver.*

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* There are many natural phenomena which are apparently opposed to the existence of this property in bodies. The familiar instance of a nail being driven into wood, from what has already been said, cannot be regarded as adverse to the view of the impenetrability of matter; for there is in this case, as when the hand is plunged into water, a mere separation of parts.

The porosity of bodies is a great cause of deception regarding this property. If a quantity of spirit of wine be placed in a glass,—no less than *twenty times its bulk* of fine cotton-wool may be introduced into the spirit without perceptibly altering the bulk of the liquid. This is owing to the extreme porosity of the cotton, or the large spaces which exist between its particles, so that the actual mass or quantity of matter introduced is really small.

A still more remarkable instance of the apparent penetrability of matter occurs in the chemical combinations of certain liquids and gases. As an example among the former, it may be stated that if 53·9 measures of alcohol be mixed with 49·8 measures of water, they make, on cooling, not 103·7 measures, but only 100. The weight of the mixture is equal to the original weights of the alcohol and water; but there is an absolute loss of bulk or volume in the proportion of nearly four measures, or one twenty-fifth part. The explanation is that, in chemical combination, the particles of one body are received into the interspaces or pores of the other body. The loss of bulk is therefore no proof that a particle of alcohol penetrates a particle of water.

To this class of cases belongs the very remarkable phenomenon, that two light bodies, by combining, may form a compound much denser than themselves. Thus two light gases, muriatic acid and ammonia, combine chemically to form a solid heavy salt, sal ammoniac. Oxygen and hydrogen combine to produce water, and the condensation here is so great, that the water occupies only 1–2000th of the space of the gases which produce it! The light metal, potassium, which floats on water, combines with oxygen gas to form a body much heavier than water. In all of these instances there is probably, during combination, a much closer approximation of the particles of matter than that which exists in the bodies separately. The density of the compound increases, because an infiniely greater number of particles become packed within the same

These are the two *essential* properties of matter. They exist in the largest masses as well as in the minutest particles; and without them we should have no idea of matter, or of the material nature of the constituent parts of the universe. There is, however, another property which demands consideration, but this appertains to masses of matter, namely:—

6. DIVISIBILITY. By this property a body admits of being divided into numerous parts. A lump of marble may be reduced by mechanical means to the state of a fine powder. If the minutest grain be placed under a good microscope, it will appear like a large block, and therefore still capable of division. When it is so reduced that one of its particles has a diameter of not more than 1–500,000th part of an inch, it becomes altogether invisible to the eye, even when placed in the field of the most powerful microscope. Matter may, however, be still further divided. A single *grain* of gold may by the great ductility of this metal, be drawn into wire so fine that its divisibility is calculated at not less than three thousand six hundred millions of visible parts. It may be proved experimentally, that half a grain of indigo will give a deep blue colour to one hundred and fifty ounces of water; and Professor Muncke, an eminent philosopher of Heidelberg, has calculated that a *grain* of this substance may be thus divided into *five hundred billions* of visible parts![*] There is no doubt that the great phenomena manifested in the chemical changes of bodies take place among particles even more minute than these. But the question will naturally arise whether there is any limit to this property of matter? Whether, in other words, matter is or is not *infinitely divisible?*

A mathematician can demonstrate by simple rules, that a

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space. Gold and platina may be rendered denser by hammering: this does not prove that the particles penetrate or are driven into each other, but merely that they are brought closer together: and what is here effected on a small scale by a mechanical force, is in the other instances produced on a large scale by the extraordinary power of chemical attraction. Even the diamond diminishes in size, or contracts, when exposed to a very low temperature; a fact which proves that pores must exist between the particles of a body, the dimensions of which cannot be reduced by any mechanical force.

[*] In order to convey an idea of the enormous divisibility which a grain of indigo undergoes when thus diffused in water, it may be stated, that to count a *billion* at the rate of 150 per minute, would require the incessant labour of a period of 12,683 years!

straight line may be divided or intersected *ad infinitum.* These rules, however, do not apply to the properties of matter. Although the philosopher is unable to assign a limit to the divisibility of a body into parts, yet there are many facts in chemistry which tend to show that such a limit must exist. Bodies in masses are found to combine together in fixed and unalterable weights; and it is only reasonable to infer, that what is true of the mass is true of its parts; and therefore that these weights represent the weights of the *atoms*[*] or ultimate particles of bodies. From these considerations, therefore, we arrive at the conclusion that there is a limit to the divisibility of matter, although it is impossible for the mind to form an idea of the size of the ultimate particles.[†]

7. ATTRACTION.[‡] This, in one of its forms, is a most important attribute of matter; upon it the great theory of the Solar system, and the explanation of astronomical phenomena are essentially based. By the term attraction, in its most simple sense, we are to understand that property, whereby one body is drawn to, or approaches to, another when free to move. There are several species of attraction, which are probably only modifications of one great force pervading all material bodies. When this force is exerted between the minute or ultimate particles of matter, it is called COHESION, or the attraction of aggregation, and according to the degree in which it exists, so is a body solid, liquid, or gaseous. When, however, attraction takes place between

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[*] From *α* priv. and *τέμνειν* to cut, signifying that the particle cannot be cut, or that it will admit of no further division. To speak of a *divisible atom* would therefore be a solecism. The atomic theory is wholly opposed to the infinite divisibility of matter.

[†] Of the non-essential properties of matter, *porosity* and *elasticity*, it is scarcely necessary to speak. Some facts already stated prove that the particles of matter are not in contact. All bodies, whether solid, liquid, or aeriform, may, by mechanical and chemical means, be reduced to a smaller bulk. There are, therefore, interstitial spaces between the particles, and these are called pores. The most porous body is that which, with the least mass, has the greatest volume. No two bodies are precisely similar to each other with respect to porosity. *Elasticity* is a property by which a body, when it has been reduced in volume, or has undergone any alteration of form, is capable of resuming its original volume and form, so soon as the disturbing force has ceased to act. It is obvious that the properties of porosity and elasticity can apply only to masses of matter.

[‡] From *attraho* to draw, because one body appears to draw another to itself.

large masses of matter, and at visible or perceptible distances, it is called GRAVITATION.

8. GRAVITATION or GRAVITY. This is that form of attraction which more particularly concerns the astronomer. Thus the planets are attracted or drawn to the sun by the force of gravity; and but for a counteracting force they would be speedily drawn into it. In the same way the moons or satellites are attracted by the planets around which they revolve. All bodies on the surface of the earth are drawn to it by a similar force, exerted by the mass of the earth: thus, what is called *weight* is expressive of the gravity of a body,—the measurement of the force or power by which it is attracted to the earth: in other words, weight may be defined to be the resisted effect of the earth's attraction. It is important to remember that, as every particle of matter is endowed with this property, the attraction between two bodies is reciprocal: thus, the smallest body in the act of falling, while it is attracted, also exerts an attractive power on the earth itself.

The two simple laws upon which the great theory of gravitation is based, were first determined by Newton. They are—

1. That the force of gravitation between two bodies is in a direct ratio to their mass *; and,
2. That this force, like all radiant forces, or forces emanating from a centre, is in an inverse ratio to the square of the distance of one body from the other.

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* By the *mass* of a body we are to understand the number of material particles which it contains;—the greater the number of these particles, the greater the mass; and as each particle exerts a power of attraction, the greater the general force of gravitation. The mass of a body must not be confounded with its *density*, as this is nothing more than a comparison of masses under equal bulks. A mass of lead which contains as many particles as a mass of gold, will exert an equal power of attraction; but the bulks or volumes of the two bodies will be very different, since the particles of gold are closer to each other, or, in other words, a greater number are contained in an equal space. Hence we say gold is denser than lead, for if we take a cubic inch of each metal, and compare their weights or gravitating forces, we shall find that the mass of gold is greater than that of lead, in the ratio of about 19 to 11. If the earth were formed of gold, the force with which bodies would be attracted to it would be nearly twice as great as if it were formed of lead; for the attraction is in a direct ratio to the mass, and as the mass of lead is only one half of the mass of gold, so would the relative gravitating force be proportionally reduced.

nce, it follows, that if the mass of one body be one hun-
imes greater than that of another, the force of gravi-
will be in the same proportion, *i. e.* one hundred times
r. Thus, it is undoubtedly true that while the earth
ts all terrestrial bodies towards itself, so is it attracted
ds them in return; but as their masses are infinitely
compared with the mass of the earth, the degree in
the latter is attracted by them is quite imperceptible

In the same way as the mass of the sun is immensely
compared with the mass of the earth, being in the
of 354,936 to 1, it follows that the attraction of the
can exert but little effect upon the sun.*

an illustration of the second law it may be stated, that
a body is removed to twice a given distance from
er body, the force of gravitation is reduced to one-
; at three times the distance to one-ninth; and at
imes the distance to one-sixteenth. Thus, if of two
ts in the solar system, one be twice as distant from the
s the other, the attractive power of the sun, acting upon
ore distant planet, is reduced not to one-half, but to
ourth of that which is exerted upon the nearer planet.

nce, it may be stated, as a further expression of this
that the mutual attraction of two bodies will increase
same proportion as their masses are increased, and as
uare of their distance from each other is decreased.

is important to bear in mind, in reference to the laws of
ty, that in all masses of a spherical, or nearly spherical
the attraction or gravitating power is precisely the
as if the whole matter of each sphere were collected in
ntre, and the spheres were single particles there placed.
, as it will be presently explained, in calculating the
of what has been designated *terrestrial* gravity, as it
ds falling bodies, in contradistinction to the *universal*
ty manifested between the planets of the solar system,
w of decrease and increase must always be calculated
the earth's centre. Hence, it is only at a distance from
rface equal to one-half of the earth's diameter, that the
of gravity would become reduced to one-fourth of what

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he sun is no less than 1,377,613 times larger than the earth, but
nsity of its substance is only one-fourth that of the earth; and it
en already explained that the force of attraction is not in a ratio to
e or bulk, but to the quantity of matter present in a body. The
or interspaces exert no attractive force.

it is upon the surface; and in a like proportion for smaller distances: but no distance to which man has access, can make the slightest apparent difference in the amount of this force.

9. INERTIA is not, as it is often defined to be, a tendency in matter to *resist* any change, but absolute passiveness, or perfect indifference to rest or motion. Inertia is synonymous with inactivity: it signifies a total absence of power in matter to change its condition of rest or motion. Hence, it follows, from this attribute of matter that, except by the application of some external force, a body cannot commence to move from a state of rest, nor when once in motion can it again resume a state of rest, except by the operation of some external cause.* But inertia is manifested in other conditions. Neither the *quantity* nor *direction* of motion, once imparted to a body, can be increased or diminished, or in any way altered spontaneously in the body. If such a change ensue, it is certain that some cause independently of the moving body is operating to produce it, for it is obvious that whatever would enable a body to increase or diminish the amount of its motion, or to change the direction in which it moved, would equally enable it to move itself; but this, as we know, is impossible. The inertia of a body at rest is measured by its force of gravity, or the weight required to move it: the inertia of a body in motion is measured by its mass multiplied by its velocity, and is commonly called *momentum*.

The inertia of matter is strikingly shown in many astronomical phenomena. Thus, the impulse given to the earth at its creation, by which it is carried in its orbit round the sun, has continued unchanged; and that motion round its axis, which was simultaneously imparted to it, to which the changes of night and day are owing, has apparently undergone no alteration. If the earth's motion had slackened by the hundredth part of a second in a revolution, and had continued to slacken in this proportion, the day would have been already lengthened by six hours in the six thousand years which have elapsed since the history of the world began, and if we suppose a longer period to precede or follow, the day might be increased a month, or to any length.* While there has been no alteration in the amount of motion, the direction of the motion has equally continued unchanged; or if any disturbing causes have affected it, they have been due to the attraction of the other planetary bodies, and have in time undergone a complete compensation, so that the stability of the universe is dependent on the inertia of matter — *i. e.* its utter passiveness to spontaneous changes, in the quantity or direction of the motion originally imparted to the planetary bodies having undergone no change.

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* "The language sometimes used to explain the property of inertia, in popular works, is eminently calculated to mislead the student. The term, resistance or stubbornness to move, is faulty in this respect. It implies as strongly the absence of all resistance to the reception of motion, as it does the absence of power to move itself. The term, *vis inertiæ*, or *force of inactivity*, so frequently used, even by authors pretending to scientific accuracy, is still more reprehensible. It is a contradiction in terms; the term *inactivity* implying the absence of all force." — *Lardner's Cyclopædia — Mechanics.*

10. ABSOLUTE AND RELATIVE MOTION. By the motion of a body we are to understand simply its change of place, and from what has been stated respecting the inertia of matter, a cause must always exist for it. Motion is sometimes only apparent, as, for instance, the motion of the sun, which is really due to the motion of the earth, the spectator imagining the earth to be in a state of absolute rest, while it has a rapid motion on its axis as well as in its orbit. A state of absolute rest is probably unknown in nature, for the earth and all bodies upon its surface are continually in motion; and even the sun, although at rest compared with the earth, has not only a periodic motion around a common centre of gravity, but, according to some modern researches, it makes a rapid revolution around a remote centre. A body is said to be in *absolute* motion, when its situation is changed with respect to some other body or bodies apparently at rest; and to be *relatively* in motion, when compared with other bodies which are likewise in motion.†

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* Whewell's Astronomy and General Physics.

† Astronomers consider it as an established fact, that the Newtonian law of gravitation extends throughout the sidereal space, and governs the motions of the stars. It has been lately announced by Professor Mädler, of Dorpat, that the group of the Pleiades may be taken as the great central point of the universe, around which the solar system and all the stars revolve. He has come to this conclusion, because the velocity of motion in the fixed stars gradually increases in all directions as they recede from this group. He fixes upon the star *Alcyone*, as probably being the *Great Central Sun* of the solar and stellar system. The distance of this star from our sun he calculates at 34 millions of radii of the earth's orbit (or 3230 billions of miles), and he concludes that our sun accomplishes one entire revolution around Alcyone in 18,200,000 years

When a body always passes over equal parts of space in equal successive portions of time, its motion is said to be *uniform.*

When the successive portions of space described in equal times continually increase, the motion is said to be *accelerated*, as in a body falling to the earth; and if the successive portions of space continually decrease, the motion is said to be *retarded*, as in a heavy body projected into the air before it begins to fall. Also, the motion is said to be *uniformly* accelerated or retarded, when the increments or decrements of the spaces, described in equal successive portions of time, are always equal.

11. The VELOCITY of a body, or the rate of its motion, is measured by the space or distance passed over in a given time.*

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moving in its orbit at the rate of 36·8 English miles in a second!—*Athenæum.*

"Our sun, viewed in relation to the planets which revolve around it, may be regarded as at rest, although it revolves around the common centre of gravity of the whole system. This centre, in consequence of the varying position of the planets, falls sometimes within and sometimes without the body of the sun itself. Altogether distinct in its nature is the movement of translation of the sun—the progressive motion of the centre of gravity of the whole solar system in universal space—which is supposed to take place with such prodigious velocity, that, according to Bessel, the relative motion of the sun and the star 61 Cygni, amounts in a single day to no less than 3,336,000 miles, or more than double the velocity of the revolution of the earth in its orbit. We should be unconscious of the change of place of the solar system, were it not that, by the perfection of our astronomical instruments, and by improved methods of observation, we are enabled to note our progress by reference to distant stars, as in a vessel we estimate its speed by the apparent motion of objects on shore. The proper motion of 61 Cygni is, nevertheless, so considerable as to produce a displacement equal to a whole degree in 700 years."—*Humboldt's Cosmos.* Hence the term "fixed" is no longer strictly applicable to the stars. According to the researches of Argelander, the sun, with the planets, is actually moving towards the constellation Hercules; and very probably towards a point which, from a combination of the observations of 537 stars, was situated (equinox of 1792-1795) in 257° 49′ 7″ right ascension, and in 28° 49′ 7″ north declination.—T.

* It may be interesting here to compare certain velocities as to the space passed over in an equal period of time. Some of them are taken from Peschel (Physics, vol. i.), others are based on calculations derived from the observations of competent observers. The unit of time here assumed is a *single second*, and the space passed over, except in so far as it concerns light and electricity, is represented in English *feet*. With

12. **Force.** Whatever changes, or tends to change, the state of rest or motion of a body, is called *force*. Force is generally defined to be "whatever produces or opposes the production of motion in matter;" and in this sense it must

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respect to these two agents, the velocity of passage is so great, that even for this short period of time the space can only be represented in an intelligible form in *miles*. — T.

	Miles.
Light	192,500
Electric fluid, not less than	200,000
	Feet.
Relative motion of the sun, in space	205,920
Aerolites, or shooting stars	114,000
Mean rate of the Earth's centre, in its orbit round the sun	101,061
Sound, traversing solid bodies	11,280
Sound, traversing water	4,480
Volcanic stones, projected from the volcano of Teneriffe, 1798,	3,000
A 24-pound cannon ball (maximum)	2,450
Rifle ball (maximum)	1,600
A point at the surface of the earth under the equator	1,525
A common musket ball	1,280
Air rushing into a vacuum	1,280
Volcanic stones projected from Etna	1,250
Sound, traversing air at a temperature of 60°	1,120
Sound, traversing air at 32°	1,089
A point at the earth's surface, latitude of London	950
Bullet discharged from an air-gun, air condensed to 1-100th (pressure of 1500 pounds on the square inch)	697
Flight of a Swift	252
The most violent hurricane	146
Flight of a swallow	134
Flight of an Eider duck	132
Waves in a heavy swell of the open South Atlantic Ocean	130
A hurricane	117
Locomotive engine on the North Western Railway (70 miles per hour)	102
Locomotive engine on the Great Western Railway (65 miles per hour)	95
Flight of a falcon	83
The swiftest race-horse	80
A storm	73
An ordinary race-horse	42
Flight of a crow	37
A brisk wind	36
The fastest sailing vessel	15
The current of the most rapid rivers	13
A wind of mean intensity	10
The Gulf stream (maximum)	7
An ordinary wind	6
Mean velocity of the current of rivers	4

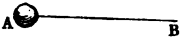
be considered as the effect of an unknown cause. If the force act but for a moment, it is called the force of percussion or impulse; if, like gravity, it act constantly and increasingly, it is called an *accelerative* force. A uniformly accelerative force is that which causes the velocity of a body to increase at an equal rate, in each successive and equal portion of time.

As consequences of the inertia of matter, the following general laws with regard to the motion of bodies have been deduced:—

GENERAL LAWS OF MOTION.

LAW I.—"*Every body perseveres in its state of rest, or uniform motion in a straight line, unless it is compelled to change that state by forces impressed thereon.*"—Newton's Princip. Book I.[*]

Thus, when a body A is positively at rest, if no external force put it in motion, it will always continue at rest. But if any impulse be given to it in the direction A B, unless some obstacle, or new force, stop or retard its motion, it will continue to move on uniformly, for ever, in the same direction A B.—Hence any projectile, as a ball shot from a cannon, an arrow from a bow, a stone cast from a sling, would not deviate from its first direction, or tend to the earth, but would continue in a straight line with an uniform motion, if the action of gravity and the resistance of the air did not alter and retard its motion.



LAW II.—"*The alteration of motion, or the motion generated or destroyed, in any body, is proportional to the force applied; and is made in the direction of that straight line in which the force acts.*"—Newton's Princip. Book I.

Thus, if any motion be generated by a given force, a double motion will be produced by a double force, a triple motion by a triple force, &c. —and considering motion as an effect, it will always be found that a body receives its motion in the same direction with the cause that acts upon it.—If the causes of motion be various, and in different directions, the body acted upon must take an oblique or compound direction. Hence a curvilinear motion cannot be produced by a simple cause, but must arise from different causes, acting at the same instant upon the body.

LAW III.—"*To every action there is always opposed an equal re-action; or the mutual actions of two bodies upon each other are always equal, and directed to contrary points.*"—Newton's Princip. Book I.

If we endeavour to raise a weight by means of a lever, we shall find the lever press the hands with the same force which we exert upon it to raise the weight. Or if we press one scale of a balance, in order to raise a weight in the other scale, the pressure against the finger will be equal to that force with which the other scale endeavours to descend.

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[*] This and the two following are generally termed *Newton*'s three laws of motion; but that he was not the first inventor of them is evident, since they are in *Descartes's Principia Philosophiæ*, Part II. pages 38, 39, and 40., which work was published before *Newton's Principia*.

When a cannon is fired, the impelling force of the powder acts equally on the breech of the cannon and on the ball; so that if the cannon, with its carriage, and the ball were of equal weight, the carriage would recoil with the same velocity as that with which the ball issues out of the cannon. But the greater the relative mass of any body, the less will its motion be, provided the force which communicates the motion continues the same. Therefore, so many times as the cannon and carriage are heavier than the ball, just so many times will the motion imparted to the cannon be less than that given to the ball.

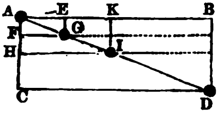
COMPOUND MOTION.

1. *If two forces act at the same time on any body, and in the same direction, the body will move more quickly than it would by being acted upon by only one of the forces.*

2. *If a body be acted upon by two equal forces, in exactly opposite directions, it will not be moved from its situation.*

3. *If a body be acted upon by two unequal forces, in exactly contrary directions, it will move in the direction of the greater force.*

4. *If a body be acted upon by two forces, neither in the same nor opposite directions, it will not follow either of the forces, but move in a line between them.*



The first three of the preceding articles may be considered as axioms, being self-evident; the fourth may be thus elucidated: — Let a force be applied to a body at A, in the direction AB, which would cause it to move uniformly from A to B in a given period of time; and, at the same instant, let another force be applied in the direction AC, such as would cause the body to move from A to C in the same time which the first force would cause it to move from A to B; by the joint action of these forces, the body will describe the diagonal AD of a parallelogram* with a uniform motion, in the same time in which it would describe one of the sides AB or AC by one of the forces alone.

For, suppose a tube equal in length to AB (in which a small ball can move freely from A to B) to be moved parallel to itself from A to C, describing with its two extremities the lines AC and BD, so that the ball may move in the tube from A to B in the same time that the tube has descended to CD; it is evident, that when the tube AB coincides with the line CD, the ball will be at the extremity D of the line, and that it has arrived there in the same time it would have described either of the sides AB or AC. The ball will likewise describe the straight line AD, for by assuming several similar parallelograms AEGF, AKIH, &c. it will appear, that while the ball has moved from A to E, the tube will have descended from A to F, consequently the ball will be at G; and while the ball has moved from A to K, the tube will have descended from A to H, and the ball will be at I. Now, AGID is a straight line; for smaller parallelograms that are similar to the whole, and similarly situated, are about the same diagonal.*

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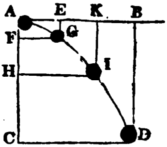
* A parallelogram is a four-sided figure, having its opposite sides parallel, and consequently equal. (EUCLID, 34 *of* I.)

5. *If a body, by a uniform motion, describe one side of a parallelogram, in the same time that it would describe the adjacent side by an accelerative force; this body, by the joint action of these forces, would describe a curve, terminating in the opposite angle of the parallelogram.*



Let ABDC be a parallelogram, and suppose the body A to be carried through AB by a uniform force in the same time that it would be carried through AC by an accelerative force, then by the joint action of these forces, the body would describe a curve AGID. For, by the preceding illustration, if the spaces AE, EK, and KB, be proportional to each other, the spaces AF, FH, and HC, will be in the same proportion, and the line AGID will be a straight line when the body is acted upon by uniform forces; but in this example, the force in the direction AB being uniform, would cause the body to move over equal spaces AE, EK, and KB, in equal portions of time; while the accelerative force in the direction AC, would cause the body to describe spaces AF, FH, and HC, increasing in magnitude in equal successive portions of time; hence the parallelograms AEGF, AKIH, &c. are not about the same diagonal†: therefore AGID is not a straight line, but a curve.

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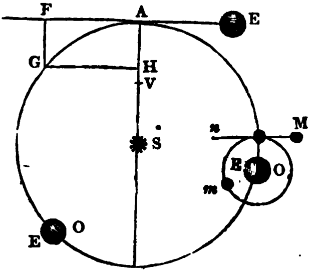
* EUCLID, 26 *of* VI.

† EUCLID, 24 *of* VI.

6. *The curvilinear motions of all the planets arise from the uniform projectile forces of bodies in straight lines, and the universal power of attraction which draws them off from these lines.*



If the body E be projected along the straight line EAF, in free space where it meets with no resistance, and is not drawn aside by any other force, it will (by the first law of motion) go on for ever in the same direction, and with the same velocity. For, the force which moves it from E to A in a given time will carry it from A to F in a successive and equal portion of time, and so on; there being nothing either to obstruct or alter its motion. But if, when the projectile force has carried the body to A, another body, as S, begins to attract it, with a power duly adjusted and perpendicular to its motion at A, it will be drawn from the straight line EAF, and revolve about S in the circle* AGOOA. When the body E arrives at O, or any other part of its orbit, if the small body M, within the sphere of E's attraction, be projected, as in the straight line M *n*, with a force perpendicular to the attraction of E, it will go round the body E, in the orbit *m*, and accompany E in its whole course round the body S.—Here S may represent the sun, E the earth, and M the moon.

If the earth at A be attracted towards the sun at S, so as to fall from A to H by the force of gravity alone, in the same time which the projectile force singly would have carried it from A to F; by the combined action of these forces it will describe the curve AG; and if the velocity with which E is projected from A, be such as it would have acquired by falling from A to V (the half of AS) by the force of gravity alone†, it will revolve round S in a circle.

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* If any body revolve round another in a circle, the revolving body must be projected with a velocity equal to that which it would have acquired by falling through half the radius of the circle towards the attracting body. EMERSON'S *Cent. Forces*, Prop. ii.

† It is proper to remark, that the time occupied by a body in taking the curvilinear course from A to G in the diagram, is precisely the same as if it fell at once by the force of gravity from A to H, although the

7. *If one body revolve round another (as the earth round the sun), so as to vary its distance from the centre of mo-*

distance is obviously much greater. This arises from the velocity of motion being always proportionate to the force or power producing it. and to its being sufficient for a certain period to counteract the force of gravity. All bodies which fall to the earth, or are drawn to its surface by gravity, pass through very unequal spaces in equal times, not owing to any variation in the force of gravity itself; for from the enormous distance of the centre of the earth, no change can be detected, but to their acquiring an accelerated motion by the constant action of this force.

So great is the velocity of a falling body, that the eye cannot follow it; but by the employment of an ingenious apparatus it easily admits of measurement. Thus it has been ascertained that in the latitude of London, a body falls in vacuo $16\frac{1}{12}$ feet during the first second of its descent, and at the end of this time it has acquired such an increase of velocity as would carry it through double that space, or $32\frac{1}{6}$ feet in the next second of time, if the force of gravity were to cease acting upon it; but the velocity continuing to increase by the power of gravity continuing to act upon the body, it actually passes during this second over three times as much space as it passed over in the first second: this added to one makes four. In the third second, five times the space, which added to the four makes nine, and so on, always increasing by the odd numbers: hence we obtain for the descent of circumterrestrial bodies this simple rule — *The spaces passed over are directly as the squares of the times.* Now, as in the first second of time a body falls through $16\frac{1}{12}$ feet, in order to find the space a body passes through in its descent, we have only to square the seconds, and multiply the product by $16\frac{1}{12}$ feet. To the power of gravity, therefore, considered as a constant force, we are to ascribe the descent of every projectile in a curved line.

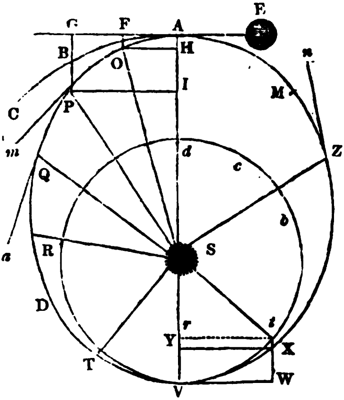
The following may be taken as a summary of our knowledge with regard to the course of bodies acted on by two forces, one of which is of an accelerative kind: —

1. A body projected horizontally moves in the direction of the projectile force, through a space equal to that which it would have described had it been acted on by that force alone; but arrives at a point as much below that from which it started, as it would have reached had it fallen freely in the same time.

2. A body descends towards the earth through the same space that it would have fallen had it obeyed the force of gravity only, during the time of its motion, inclining each moment from the original perpendicular as far in the direction of the projectile force as this would have carried it in the same time.

3. A body projected horizontally reaches the earth in exactly the same time that it would have fallen freely from the same height. (*Peschel's Physics*, vol i.)

The last conclusion leads to what may appear an extraordinary statement, namely, that a cannon-ball fired point blank from a cannon touches the ground, in exactly the same period of time as if it had been dropped perpendicularly from its mouth! The projectile force of the powder is in the first instance so much greater than the force of gravity, that the *tion, the projectile and centripetal forces must each be variable, and the path of the revolving body will differ from a circle.*



Thus, if while a projectile force would carry a planet from A to F, the sun's attraction at S would bring it from A to H, the gravitating power would be too great for the projectile force; the planet, therefore, instead of proceeding in the circle ABC (as in the preceding article), would describe the curve AO, and approach nearer to the sun; SO being less than SA. Now, as the centripetal force, or gravitating power, always increases as the square of the planet's distance from the sun diminishes*, when the planet arrives at O the centripetal force will be increased, which will likewise increase the velocity of the planet, and accelerate its motion from O to V; so as to cause it to describe the arcs OP, PQ, QR, RD, DT, TV, successively increasing in magnitude, in equal portions of time. The motion of the planet being thus accelerated, it gains such a centrifugal force, or tendency to fly off at V, in the line VW, as overcomes the sun's attraction; this centrifugal or projectile force being too great to allow the planet to approach nearer the sun than it is at V, or even to move round the sun in the circle *tbcd*, &c., it flies off in the curve XZMA, with a velocity decreasing as gradually from V to A, as if it had returned through the arcs VT, TD, DR, &c. to A, with the same velocity which it passed through these arcs in its motion from A, towards V.

ball has already gone a considerable distance in a straight direction before this constant force of gravity begins in any degree to affect its motion. When the projectile force becomes lessened, the ball descends in a parabolic curve, — according to the law already explained. Hence, in falling through a given space, it describes in the first instance a very long curve; in the next equal period of time, it makes a shorter curve by falling through three times that space, and thus rapidly reaches the ground.—T.

* Newton's *Princip. Book III.* Prop. II.

At A the planet will have acquired the same velocity as it had at first, and thus by the centrifugal and centripetal forces it will continue to move round S.

Two very natural questions may here be asked; *viz.* why the action of gravity, if it be too great for the projectile force at O, does not draw the planet to the sun at S? and why the projectile force at V, if it be too great for the centripetal force, or gravity, at the same point, does not carry the planet farther and farther from the sun, till it is beyond the power of his attraction?

First. If the projectile force at A were such as to carry the planet from A to G, double the distance, in the same time that it was carried from A to F, it would require four* times as much gravity to retain it in its orbit, *viz.* it must fall through AI in the time that the projectile force would carry it from A to G, otherwise it would not describe the curve AOP. But an increase of gravity gives the planet an increase of velocity, and an increase of velocity increases the projectile force; therefore, the tendency of the planet to fly off from the curve in a tangent P*m*, is greater at P than at O, and greater at Q than at P, and so on; hence, while the gravitating power increases, the projectile power increases, so that the planet cannot be drawn to the sun.

Secondly. The projectile force is the greatest at, or near, the point V, and the gravitating power is likewise the greatest at this point. For if AS be double of VS, the centripetal force at V will be four times as great as at A, being as the square of the distance from the sun. If the projectile force at V be double of what it was at A, the space VW, which is the double of AF, will be described in the same time that AF was described, and the planet will be at X in that time. Now, if the action of gravity had been an exact counterbalance for the projectile force during the time mentioned, the planet would have been at *t*, instead of X, and it would describe the circle *t b c*, &c.; but the projectile force being too powerful for the centripetal force, the planet recedes from the sun at S, and ascends in the curve XZM, &c. Yet, it cannot fly off in a tangent in its ascent; because its velocity is retarded, and consequently its projectile force is diminished, by the action of gravity. Thus, when the planet arrives at Z, its tendency to fly off in a tangent Z*n*, is just as much retarded, by the action of gravity, as its

* Ferguson's Astronomy, Art. 153.

motion was accelerated thereby at Q; therefore it must be retained in its orbit.

The figure which has been here employed for illustration must not be considered as representing the true form of the earth's orbit round the sun. Although it is customary to describe this orbit as an ellipse, it should be explained that in reality it differs but little from a circle. The excentricity of the earth, being the distance of the sun's station from the centre of the earth's orbit, is equal to 1,579,579 miles. In winter the earth is nearer to the sun by twice the excentricity, or 3,159,158 miles. This is only about one-thirtieth part of the whole distance, and it makes a difference of less than one-sixtieth in the diameter of the earth's orbit, a quantity which scarcely affects its circular form. That we are nearer to the sun in winter than in summer is proved by the fact that on the 21st December the apparent diameter of this luminary is 32′ 34″, and on the 21st June only 31′ 31″. — T.

CHAPTER III.

Of the Figure of the Earth, and its Magnitude.

THE figure of the earth, as composed of land and water, is nearly spherical. The ancients held various opinions respecting its figure; some imagined it to be cylindrical, or in the form of a drum; but the general opinion was that it was a vast extended plane, and that the horizon was the utmost limit of the earth, and the ocean the boundary of the horizon. These opinions were held in the infancy of astronomy; and, in the early ages of Christianity, some of the Fathers went so far as to pronounce it *heretical* for any person to declare that the earth was round, or that there were antipodes. But by the industry of succeeding ages, when astronomy and navigation were brought to a tolerable degree of perfection, and when it was observed that the moon was frequently eclipsed by the shadow of the earth, and that the shadow always appeared circular on the *disc* or face of the moon, in whatever position the shadow was projected, it necessarily followed that the earth, which cast the shadow, must be spherical; since nothing but a sphere, when turned in every position with respect to a luminous body, can produce a circular shadow. In addition to this, the calculations of eclipses, and of the places of the planets, are made upon the supposition that the earth is a sphere, and they all answer to the true times, when accurately calculated. When an eclipse of the moon happens, it is observed sooner by those who live eastward than by those who live westward; and, by frequent experience, astronomers have determined that, for every fifteen degrees difference of longitude, an eclipse begins an hour sooner in the easternmost place, and an hour later in the westernmost. If the earth were a plane, eclipses would happen at the same time in all places, nor could one part of the world be deprived of the light of the sun while another part enjoyed the benefit of it. The voyages of circumnavigators sufficiently prove that the earth is round from west to east. The first who attempted to circumnavigate the globe was Magellan, a Portuguese, who sailed from Seville in Spain on the 10th of August 1519; he did not live to return, but his ship arrived at St. Lucar, near Seville, on the 7th of September 1522, without altering its direction, except to the north or south, as compelled by the winds or intervening land. Since this period, the circumnavigation of the globe has been performed at different times by Sir Francis Drake, Lord Anson, Captain Cook and others. The voyages of these circumnavigators have been frequently adduced by writers on geography and the globes, to prove that the earth is a sphere; but when we reflect that all of them sailed westward round the globe (and not northward and southward round it), it is evident that they might have performed the same voyages had the earth been in the form of a drum or cylinder; but the earth cannot be in the form of a cylinder, for if it were, then the difference of longitude between any two places would be equal to the meridional distance between the same places, as on a Mercator's chart, which is contrary to observation. Again, if a ship sail in any part of the world, and upon any course whatever, on her departure from the coast, all high towers or mountains gradually disappear, and persons on shore may see the masts of a ship after the hull is hidden by the convexity of the water (*see Figure* III. *Plate* I.). If a vessel sail northward, in north latitude, the people on board may observe the polar star gradually to increase in altitude the farther they go; they may likewise observe new stars continually emerging above the horizon, which were before imperceptible; and at the same time those stars which appear southward, will continue to diminish in altitude till they become invisible. The contrary phenomena will happen if the vessel sail southward; hence the earth is spherical from north to south, and it has already been shown that it is spherical from east to west.

The arguments already adduced clearly prove the rotundity of the earth, although common experience shows us that it is not strictly a geometrical sphere; for its surface is diversified with mountains and valleys: but these irregularities no more hinder the earth from being reckoned spherical, considering its magnitude, than the roughness of an orange hinders it from being considered round.*

When philosophical and mathematical knowledge arrived at a still greater degree of perfection, there seemed to be a very sufficient reason for the philosophers of the last age to consider the earth not truly spherical, but rather in the form of a spheroid.† This notion first arose from observations

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* Our largest globes are in general 18 inches in diameter. The diameter of the earth is about 7964 miles. Chimborazo, one of the highest of the Andes, is about 21,440 feet, or about four miles high. The radius of the earth is 3982 miles, and that of an 18-inch globe 9 inches. Now, by the rule of three, 3982 m. : 3982 m. + 4 :: 9 in. : 9·009, from which deduct the radius of the artificial globe, the remainder ·009 $= \frac{9}{1000} = \frac{1}{111}$ of an inch, nearly, is the elevation of the Andes on an 18-inch globe, which is considerably less than a grain of sand. One of the highest points of the Himalaya mountains to the north of Hindostan, surveyed by Capt. Blake, and deduced from his observations by Mr. Colebrooke, is 28,015 feet above the level of the sea; but this would not be equal on such a globe to a grain of sand, and could not even admit of any apparent elevation on a sphere three feet in diameter. (*Edinburgh Philosophical Journal*, vol. v. p. 408.)

† A spheroid is a figure formed by the revolution of an ellipsis about its axis, and an ellipsis is a curvilinear figure in geometry, formed by cutting a cone or cylinder obliquely without including the base; but its nature will be more clearly comprehended, by the learner, from the following description.

Let TR (in *Plate* IV. *Figure* V.) be the transverse diameter, or longer axis of the ellipsis, and CO the conjugate diameter, or shorter axis. With the distance TD or DR in your compasses, and C as a centre, describe the arc Ff: the points F, f, will be the two foci of the ellipsis. Take a thread of the length of the transverse axis TR, and fasten its ends with pins in F and f, then stretch the thread FIf, and it will reach to I in the curve; then by moving a pencil round with the thread, and keeping it always stretched, it will trace out the ellipsis TCRO.—If this ellipsis be made to revolve on its longer axis TR, it will generate an *oblong spheroid*, or *Cassini*'s figure of the earth; but if it be supposed to revolve on its shorter axis CO, it will form an *oblate spheroid*, or Sir Isaac Newton's figure of the earth.—The orbits or paths of all the planets are ellipses, and the sun is situated in on pendulum clocks[*], which being fitted to beat seconds in the latitudes of Paris and London, were found to move more slowly as they approached the equator; and at, or near, the equator, it was found necessary to shorten the pendulum about $\frac{1}{8}$ of an inch, to make the clock agree with the times of the stars passing the meridian. This difference appearing to Huygens[†] and Sir Isaac Newton, to be a much greater quantity than could arise from the alteration in the length of the pendulum by the effect of heat only, they separately arrived at the conclusion that the earth was flatted at the poles, or, in other words, that there was a greater thickness in the equatorial than in the polar diameter.[‡] By the revolution of the earth on its axis (admitting it to be a sphere) the centrifugal force at the equator would be greater than the centrifugal force in the latitude of London or Paris, because a larger circle is described by the equator in the same time: but as the centrifugal force (or tendency which a body has to recede from the centre) increases, the action of gravity necessarily diminishes; and where the action of gravity is less, the vibrations of pendulums of equal lengths become slower: hence, supposing the earth to be a sphere, we have two causes why a pendulum should move more slowly at the equator than at London or Paris, *viz.* the action of heat which expands all metals, and therefore lengthens the pendulum, and the diminution of

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one of the *foci* of the earth's orbit, as will be observed farther on.—The points F, f, are called foci; because if a ray of light issuing from the point F meet the curve in the point I, it will be reflected back into the focus f. For lines drawn from the two foci of an ellipsis to any point in the curve, make equal angles with a tangent to the curve at that point; and by the laws of optics the angle of incidence is equal to the angle of reflection. (*Robertson*'s Conic Sections, Book III. Scholium to Prop. ix.)

[*] Philosophical Transactions, No. 386.

[†] A celebrated mathematician, born at the Hague in Holland, in 1629.

[‡] The length of a pendulum at the equator is to the length of a pendulum at the pole as the axis of the earth is to the equatorial diameter. (*Emerson*'s Math. Geog. Prop. XI.) M. Laplace (*Exposition du Systême du Monde*) has shown, that if the force of gravity at the equator be represented by 1, at the poles it will be 1·00567; and at the intermediate latitudes of 30°, 45°, 52°, and 60°, it will be 1·00141, 1·00283, 1·00357, and 1·00423 respectively, and these numbers will represent the ratios between the lengths of pendulums vibrating *seconds* in these different latitudes. The length of a pendulum at the equator is 39·06 inches, at the poles 39·281, and in latitudes 30°, 45°, 52°, and 63°, the respective lengths are 39·115, 39·17, 39·2, and 39·225.

gravity as an effect of the increase of the centrifugal force.* But these two causes combined would not, according to Sir Isaac Newton, produce so great a difference as to require the pendulum to be shortened $\frac{1}{8}$th of an inch for the vibration of seconds: he therefore supposed the earth to assume the same figure that a homogeneous fluid would acquire by revolving on an axis, *viz.* the figure of an oblate spheroid, and found that the "diameter of the earth at the equator is to its diameter from pole to pole as 230 to 229."† Notwithstanding the deductions of Sir Isaac Newton, on the strictest mathematical principles, many of the philosophers in France, the principal of whom was Cassini ‡, asserted that the earth was an oblong spheroid, the polar diameter being the longer; and as these different opinions were supposed to retard the general progress of science in France, the king resolved that the affair should be determined by actual admeasurement at at his own expense. Accordingly, about the year 1735, two companies of the most able mathematicians of that nation were appointed: the one to measure the degree of a meridian as near to the equator as possible, and the other company to perform a like operation as near the pole as could be conveniently attempted. The results of these admeasurements contradicted the assertions of Cassini, and of J. Bernouilli (a celebrated mathematician of Bâsle in Switzerland, who warmly espoused his cause), and confirmed the calculations of Sir Isaac Newton.—In the year 1756, the Royal Academy of Sciences of Paris appointed eight astronomers to measure the length of a degree between Paris and Amiens; the result of their admeasurement gave 57069 toises* for the length of a degree.

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* The pendulum is a falling body, and therefore has a direct relation to the earth's attraction or gravity. The greater this attracting force, or the less it is interfered with by other forces, the more rapid the vibration, and *vice versâ*; hence the pendulum is employed to determine the amount of centrifugal force and the intensity of the earth's attraction. Lieutenant Colonel Sabine has ascertained, by his pendulum experiments, the curious fact that there is a greater intensity of gravitation in volcanic islands than in other localities. The rate of a pendulum may be determined with proper care to a single tenth of a second *per diem*, while the variation of rate occasioned by the geological character of stations has amounted, in extreme cases, to nearly ten seconds *per diem*. — T.

† Motte's translation of Newton's Principia, Book III. page 243. Calling the equatorial diameter of the earth 7964 English miles, the polar diameter will be 7929. — For 230 : 229 :: 7964 : 7929 miles, the polar axis. Hence the polar axis is shorter than the equatorial diameter by 35 miles, and the earth is higher at the equator than at the poles by $17\frac{1}{2}$ miles, a difference imperceptible on the largest globes that are made. — Suppose a globe to be 18 inches in diameter at the equator, then 230 : 229 :: 18 : $17\frac{106}{115}$, the polar diameter; the difference of the diameters is $\frac{9}{115}$ of an inch, half difference is $\frac{9}{230}$ of an inch, the flatness of an 18-inch globe at each pole, which is less than the 23d part of an inch, or not much thicker than the paper and paste, a quantity not to be discovered by the appearance; and on smaller globes the difference would be considerably less.

‡ Son of the celebrated Italian astronomer; he was born at Paris in 1677.

The utility of finding the length of a degree, in order to determine the magnitude and figure of the earth, may be rendered familiar to a learner thus: Suppose I find the latitude of London to be 51½° north, and travel due north till I find the latitude of a place to be 52½° north, I shall then have travelled a degree, and the distance between the two places, accurately measured, will be the length of a degree. Now, if the earth be a correct sphere, the length of a degree on a meridian, or a great circle, will be equal all over the world, after a proper allowance has been made for elevation of the ground; the length of a degree multiplied by 360 will give the circumference of the earth, and hence its diameter will be easily found; but if the earth have any other figure than that of a sphere, the length of a degree on the same meridian will be of course different in different latitudes, and if the figure of the earth resemble an oblate spheroid, the lengths of a degree will increase as the latitudes increase.† The English translation of Maupertuis's figure of the earth concludes with these words: (*see page* 163 *of the work*) "*The degree of the meridian which cuts the polar circle being longer than a degree of the meridian in* France, *the earth is a spheroid flatted towards the poles.*" For, the longer a degree is, the greater must be the circle of which it is a part; and the greater the circle is, the less is its curvature.

The first person who measured the length of a degree with any appearance of accuracy was Mr. Richard Norwood: by measuring the distance between London and York, he found the length of a degree to be 367196 English feet, or 69½ English miles; hence, supposing the earth to be a sphere, its circumference will be 25020 miles, and its diameter 7964* miles; but if the length of a degree, at a medium, be 57069 toises, the circumference of the earth will be 24873 English miles, its diameter 7917 miles, and the length of a degree $69\frac{1}{10}$ miles.†

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* A toise is equal to 76·73 English inches.

† The curve would, in this case, obviously form part of a greater circle. The meridians being sections of the earth through its axis, if their figure were accurately determined, that of the earth would be at once ascertained.—T.

CONCLUSION. Notwithstanding all the admeasurements that have hitherto been made, it has never been demonstrated, in a satisfactory manner, that the earth is strictly a spheroid; indeed, from observations made in different parts of the earth, it appears that its figure is by no means that of a regular spheroid, or of any other known regular mathematical figure, and the only certain conclusion that can

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* 5280 feet make a mile, therefore 367196 divided by 5280 gives 69½ miles nearly, which multiplied by 360 produces 25020 miles, the circumference of the earth; but the circumference of a circle is to its diameter as 22 to 7, or more nearly as 355 to 113; hence 355 : 113 :: 25020 miles : 7964 miles, the diameter of the earth. Again, 6 French feet make 1 toise, therefore 57069 toises are equal to 342414 French feet; but 107 French feet are equal to 114 English feet, hence 107 F. f. : 114 E. f. :: 342414 F. f. : 364814 English feet, which divided by 5280, the feet in a mile, gives 69·09 miles, the length of a degree by the French admeasurement. Or, 342414 multiplied by 360 produces 123269040 French feet, the circumference of the earth, and 107 : 114 :: 123269040 : 131333369 English feet, equal to 24873·74 miles, the circumference of the earth, and 355 : 113 :: 24873·74 : 7917 miles, the diameter of the earth.

† The length of a degree in lat. 51° 9′ N. is 364950 feet = 69·12 English miles. Trigonometrical Survey of England and Wales, Vol. II. Part II. page 113. Mr. Swanberg, a Swedish mathematician, found the length of a degree to be 57196·159 toises = 365627·782 English feet = 69·247 miles.

[According to Laplace, the celebrated French astronomer, the earth's equatorial diameter is 7924 miles; and Sir J. F. W. Herschel (See Cab. Cyc. ASTRONOMY) gives the following dimensions, which appear to be the most accurate of any that have yet been published: —

	Feet.	Miles.
Greater or equatorial diameter - -	41,847,426 =	7925·648
Lesser or polar diameter - - -	41,707,620 =	7899·170
Difference of diameters or polar compression	139,806 =	26·478

Hence the proportion of the diameters is very nearly that of 298 : 299, and their difference $\frac{1}{299}$ of the greater, or a very little more than $\frac{1}{300}$. This amount of flattening is so slight that in a globe *three feet* in diameter, the polar axis would be only (36÷300) 0·12 inch, or about *one eighth* of an inch shorter than the equatorial axis. Such a globe, therefore, in order to represent the earth, would not differ from a sphere. In a globe 24 feet in diameter, the difference in the length of the two axes would be only one inch!] — T.

be drawn from the researches of the several philosophers who have been employed to make these measurements, is, that *the earth is rather more flat at the poles than at the equator.* The course of a ship, considering the earth a spheroid, is so near to what it would be on a sphere, that the mariner may safely trust to the rules of *globular* sailing[*], even though his course and distance were much more certain than it is possible for them to be. Hence, mathematicians content themselves with considering the earth as a sphere for all practical purposes; and artificial globes are made perfectly spherical, as the most correct representation of the figure of the earth.[†]

CHAPTER IV.

Of the Diurnal and Annual Motion of the Earth.

THE motion of the earth was denied in the early ages of the world; yet as soon as astronomical knowledge began to be more attended to, the theory of its motion received the assent of the learned, and of such as dared to think differently from the multitude, or were not apprehensive of ecclesiastical censure.—The astronomers of the last and present age have produced such a variety of strong and forcible arguments in favour of the motion of the earth, as must effectually gain the assent of every impartial inquirer. Among the many reasons for the motion of the earth, it will be sufficient to point out the following:—

1. *Of the Diurnal Motion of the Earth.*

The earth is a globe of 7912 miles in its *mean* diameter, and by revolving on its axis every 24[‡] hours from west to east, it causes an *apparent* diurnal motion of all the heavenly bodies from east to west.—We need only look at the sun, or stars, to be convinced, that either the earth, which is no more than a point* when compared with the heavens, revolves on its axis in a certain time, or else the sun, stars, &c. revolve round the earth in nearly the same time. Let us suppose, for instance, that the sun revolves round the earth in 24 hours, and that the earth has no diurnal motion.—Now, it is a known principle in the laws of motion, that if any body revolve round another as its centre, it is necessary that the central body be always in the plane in which the revolving body moves, whatever curve it describes †; therefore if the sun move round the earth in a day, its diurnal path must always describe a circle which will divide the earth into two *equal* hemispheres. But this never happens except on two days of the year, *viz.* at the time of the equinoxes, when the sun rises exactly in the east, and sets exactly in the west. For, from the 21st of March to the 23rd of September the sun rises to the north of the east, and sets to the north of the west; and from the 23rd of September to the 21st of March, it rises to the south of the east, and sets to the south of the west, and therefore its diurnal path divides the globe into two *unequal* parts.

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[*] Robertson's Navigation, Book VIII. Art. 143.

[†] From what has been already stated respecting the slight difference in the length of the polar and equatorial axes, it is obvious that no other representation on a small scale would be accurate.—T.

[‡] That is, the time from the sun's being on the meridian of any place to the time of its returning to the same meridian the next day; but the earth performs a complete revolution on its axis in 23 hours 56 minutes 4·09 seconds. (See definition 61. page 13.)

The fixed stars also (except those which lie in the equinoctial) do not appear to revolve round the *centre* of the earth, but its *axis*, in circles parallel to its equator, and diminishing in magnitude from the equinoctial to the poles; affording another very satisfactory argument in favour of the earth's rotation. If, moreover, the earth be considered immovable, the sun, whose distance from it is 95,000,000 miles, in order to complete his revolution in 24 hours, must travel at the rate of 400,000 miles per minute; and the stars, from their immeasurable distance, must revolve by millions of millions of miles more rapidly than the sun. It is also well known that the sun is above a million times larger than the earth, and it is highly probable that each of the stars is at least equal to it in magnitude: yet, if we do not admit the rotation of the earth, an infinite number of these prodigious bodies must be supposed to be perpetually circulating about our comparatively insignificant globe, not only with degrees of velocity far surpassing human conception, but exactly adapted to the respective distances of each of these individual bodies; thus introducing a *complication of motion* no less surprising than the prodigious velocity with which it would have to be performed. These improbabilities are got rid of by the simple hypothesis of the earth's revolution on its axis.

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* Dr. Keill, Lect. 26.

† Emerson's Astronomy, p. 11.

It is no argument against the earth's diurnal motion that we do not feel it; a person in the cabin of a ship, on smooth water, cannot perceive the ship's motion when it turns gently and uniformly round*; neither does the motion of the earth cause bodies to fall from its surface, for all bodies, of whatever matter they are composed, are drawn to the earth by the power of its central attraction†, which, laying hold of them according to their densities, or quantities of matter, without regard to their magnitudes, constitutes what we call weight.

[It is important that this principle should be duly impressed on the mind of the learner. All bodies, whatever their nature, or whatever their size, are attracted with equal power to the earth, unless any force opposes this attraction. It may at first be difficult to understand consistently with the law, that the power of attraction is always in a direct ratio to the mass—why a thousand pounds of iron should not fall or be attracted to the earth with greater force than a grain of the metal: but attraction influences in an equal degree *each* individual particle of matter, and when it is considered that the loftiest mountain in the world has no greater size compared with the earth, than a grain of sand on an artificial globe eighteen inches in diameter, the difference in the size of falling bodies cannot be allowed to enter into our consideration. We do not diminish the attraction of the earth for each particle by merely subdividing a material body, nor do we increase it by aggregating particles together, so as to form a larger mass. It is wholly unaffected by, and independent of, the quantity of particles; and the law, that the force is in a direct ratio to the *mass*, merely implies that when we desire to compare the relative power of attraction in two bodies, it is found to be greater in that which has the largest mass or the greater number of particles. An ounce of gold may fall to the earth in the same time as a pound; but the pound attracts the earth with greater force than an ounce, although the mass, compared with that of the earth, is so small that the reciprocal attraction in the pound of gold, is no more perceptible to our senses than that which exists in an ounce. By weighing the two, we determine the comparative number of gravitating particles in each; but the force of gravity acts equally upon the two unequal masses.

There are, however, some apparent exceptions to the law which require consideration. A grain of gold in the form of a small pellet reaches the ground or falls with such rapidity that the eye cannot follow its descent. Owing to the great malleability of gold, it may be beaten into leaves so thin that it actually becomes transparent‡, and one grain of the metal may be thus beaten out so as to cover a square seven inches and a quarter each way, or *fifty-two square inches.*[*] If this leaf of gold, weighing a grain, be dropped from the same height as the pellet, it will be observed to be a much longer time in reaching the ground, although it contains exactly the same number of gravitating particles. The difference is accounted for by the resistance offered by the atmosphere to all falling bodies, which is in a direct ratio to the extent of surface which the falling body presents. If the pellet and the leaf be dropped from a height in a vacuum, *i. e.* in a space from which the air has been artificially removed, they will reach the ground at thè same instant of time. A sovereign and a feather, allowed to fall from a given height in the air, reach the ground in very different periods, owing to the feather exposing a very large surface, compared with its mass, to the resistance of the air; but if allowed to fall in a vacuum, they touch the ground at the same instant. The sovereign weighs one hundred and twenty three grains, the feather one quarter of a grain. Therefore, the quantity of matter ($123 \times \frac{1}{4} = 492$) is nearly five hundred times greater in the gold than in the feather: yet when there is nothing to oppose the fall of the two bodies, they reach the ground at the same moment. Hence it is proved that the earth's attraction is as strongly manifested upon one as upon five hundred particles of matter, and upon five hundred as readily as upon five millions.

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* Ferguson's Astronomy, Art. 119.

† Newton's Principia, Book III. Prop. vii.

‡ The light which passes through gold leaf is of a rich sea-green colour.

These facts regarding attraction are beautifully established by the pendulum.[†] The action of the pendulum depends on gravitation, and that this force acts upon all bodies equally, and moves them with equal velocity, whatever may be the nature or the quantity of materials of which they are composed, is proved by simple observation. The motion of the pendulum is never affected by the quantity or quality of the material which constitutes the weight. In this latitude the length of a pendulum vibrating seconds should be 39·2 inches, or 39 inches and $\frac{1}{5}$ of an inch. If the pendulum have this length, the weight may be formed of gold, copper, brass, glass, or even ivory. When the vibration takes place in the atmosphere, it is merely necessary that the weight should be so great as to overcome the resistance of the air. When this has been once attained, whether the weight be doubled or trebled, or whether it be of gold or ivory, is quite immaterial; if the threads suspending the weights be of the same length, they will vibrate seconds in precisely equal periods, thus proving that gravity is acting equally on matter irrespective of its quantity and quality.

This has been lately beautifully shown in an experiment performed by Mr. Faraday. He made a pendulum of a glass bottle containing air, and he suspended in the bottle a long strip of leaf-gold, which the slightest current of air would affect and displace. The pendulum weight was thus constituted of glass, gold, and air. When vibrated, there was not the slightest displacement or motion of the gold leaf. The vibration went on for half an hour; and during the whole of this time the gold, although sometimes vertical, at others much inclined, hung in the centre of the bottle, like a stiff plate of metal, without shifting its position in the smallest degree, with respect to the air or bottle. The glass, gold, and air were equally attracted by the earth; there was nothing to counteract or interfere with this attraction. Thus, then, we establish the proposition with which we set out, that this great force on which the stability of the universe depends, acts upon matter independently of its quality or its quantity.] — T.

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[*] It would require 1500 of such leaves laid upon each other to form the thickness of a common sheet of writing paper.

[†] See page 62.

The phenomena of the *apparent* diurnal motion of the sun may be explained by the motion of the earth; thus, let IFGH (*Plate* I. *Figure* V.) represent the earth, S the sun, and the circle DSBC the apparent concavity of the heavens. Let the earth revolve on its axis, from I towards F (viz. from west to east). Suppose a spectator to be at I, the sun, which is at an immense distance, and enlightens half the globe at once, will appear to be rising. As the earth moves round, the spectator is carried towards F, and the sun seems to increase in height; when he has arrived at F, the sun is at the highest. As the earth continues to turn round, the spectator is carried from F towards G, and the altitude of the sun keeps continually diminishing; when he has arrived at G, the sun is setting. During the time the spectator has been carried from I to G, the sun has appeared to move the contrary way. Hence it is evident that while the spectator is carried through the illuminated half of the earth, it is daylight; at the middle point, F, it is noon; also, while he is carried through the dark hemisphere, it is night; and, at H, it is midnight. Thus, the vicissitude of day and night evidently appears by the rotation of the earth about its axis. What has been said of the sun is equally applicable to the moon, or any star placed at S; therefore all the celestial bodies seem to rise and set by turns, according to their various situations. The spectator at I, F, G, H, will always have his feet towards the centre of the earth, and the sky above his head, whatever position the earth may have; agreeably to the law of gravitation or attraction. Thus an inhabitant at *a* will be the most powerfully attracted towards his antipodes *b*, because the line of gravity is always in a direction towards the centre of the earth; and for the same reason *b* will be the most attracted towards *a*, *m* towards *n*, and *n* towards *m*, &c.

2. *Of the Annual Motion of the Earth.*

The diurnal revolution of the earth on its axis being proved, the annual motion round the sun will be readily admitted; for, either the earth moves round the sun in a year, or else the sun moves round the earth: now, by the laws of centripetal force, if two bodies revolve about each other, they revolve round their common centre of gravity*; and it is evident, that if the two bodies be of equal magnitude and density, or if they have equal masses, the centre of gravity will be equidistant from each body; but if these be different, the centre of gravity will be nearest to that body which has the larger mass. If the earth, therefore, remain in the same situation while the sun revolves round it, its mass must be much greater than that of the sun; for it is contrary to the laws of nature for a heavy body to revolve round a light one as its centre of motion; but from observations on the dimensions † and distances of the sun and planets, it appears that the sun so greatly exceeds, not only the earth, but the planets, in mass and magnitude, that the common centre of gravity of the whole is almost constantly within the body of the sun, so that the sun's motion round the common centre of gravity of the earth and the planets is not perceptible to ordinary observers. Not only the earth, therefore, but the planets, move round the sun, because the contrary supposition would involve an impossibility.

It is also evident that the motion of the earth in its orbit is from west to east; for if the sun be observed to rise with any fixed star which is near the ecliptic, it will, in the course of a few days, appear to the eastward of that star. And in the period of a year it will arrive at the same star again.

The earth is computed to be in its mean distance 95 millions of miles from the sun ‡, and performs its revolution round him, describing an orbit or path approaching to an elliptical form*, in 365 days 5 hours 48 minutes and 49 seconds, from any equinox or solstice to the same again; it travels at the rate of upwards of 68,000 miles per hour.† Besides this motion, which is common to every inhabitant of the earth, the inhabitants at the equator are carried 1036·5‡

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* The centre of gravity of two bodies is a certain point in a line supposed to join their centres; which point being supported, the two bodies would likewise be supported, and rest in equilibrium.

† The apparent diameters of the planets are found by a *micrometer* placed in the focus of a telescope, or, the apparent diameter of the sun may be measured by means of the projection of his image into a dark room, through a circular aperture. From these apparent diameters, and the respective distances from the earth, the real diameters of the sun and planets may be determined.

‡ In *Plate* IV. *Figure* VI. let O be the centre of the earth, P the place of an observer on its surface, and S the sun or a planet in the heavens: now to an observer at O, the sun would appear at *a*, and to an observer at P it would appear at *b*; the arc *a*, *b*, or the angle *a* S *b*, which is equal to the angle P S O, is called the horizontal parallax. Mr. Short, in vol. lii. part ii.

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of the Philosophical Transactions, has determined the horizontal parallax of the sun to be 8·65″, at its mean distance from the earth. Hence by trigonometry,

Logarithmical sine of 8·65″, or angle P S O - -	5·6219140
Is to *one* semi-diameter of the earth P O - - - -	0·0000000
As radius, sine of 90 degrees, or sign of O P S -	10·0000000
Is to 23882·84 semi-diameters - - - - - - -	4·3780860

Now if we take the diameter of the earth 7970 miles, as Mr. Short has done, the semi-diameter 3985 multiplied by 23882·84 gives 95173117 miles, the distance of the earth from the sun: if the diameter of the earth be taken 7964 miles, the distance will be 95101468 miles; if it be taken 7917 miles (see the chapter of the Figure of the Earth), the distance will be 94540222 miles. In a case of such uncertainty, where a very small error in the parallax will produce an astonishing difference in the conclusion of the process, and where an error in the diameter of the earth will also affect the operation, we may rest content with estimating the mean distance of the earth from the sun at 95 millions of miles. *Mr. Woodhouse*, in his Astronomy, page 384, calculates the sun's horizontal parallax to be 8·7017″, and at page 284., where he has given the distances of the planets from the sun according to *Laplace*, he states the distance of the earth from the sun to be 93726900 miles.

* The idea that the earth moved in an elliptical orbit was first conceived by Kepler, an eminent German astronomer, and demonstrated by Sir Isaac Newton. See the Principia, Book III. Prop. xiii.

† The earth's distance from the sun is 95 millions of miles, the mean diameter of its orbit is therefore 190 millions of miles, and the circumference of a circle is three times the diameter and one seventh more; or the circumference is to the diameter as 355 to 113 more nearly; hence 113 : 355 : : 190000000 : 596902654, the circumference of the orbit: but this circumference is described in 365 days 5 hours 48 minutes 49 seconds, or 365 days 6 hours nearly, or 8766 hours; hence 8766 h. : 596902654 m. : : 1 h. : 68092 miles *per* hour the inhabitants of the earth are carried by its annual revolution. [The relation of the diameter of a circle to its circumference, which is important in solving many astronomical problems, may be easily borne in mind by the learner by aid of the following rule:—The proportional figures are the three first odd figures 1 . 3 . 5; in pairs thus, 11 . 33 . 55: the three first of these representing 113, the diameter, and the three last, 355, the circumference.]—T.

‡ These distances are found by multiplying the number of miles contained in a degree in any parallel of latitude by 15: thus, the circumference of the earth at the equator is 360 × 69½m., and in the latitude of London it is equal to 360 × 42·95, and 24 h. : 360° × 69·1 : : 1 h. : 1035·6 m.; or 1 : 15 × 69·1 : : 1 : 1036·5 m.

miles every hour by the diurnal revolution of the earth on its axis, while those in the parallel of London are carried only about 644 miles per hour. The axis of the earth makes an angle of 23° 28′ with a perpendicular to the plane of its orbit, and has always the same oblique direction throughout its annual course*; hence it follows, that, during one part of its course, the north pole is turned towards the sun, and, during another part of its course, the south pole is turned towards it in the same proportion; which is the cause of the different seasons, as spring, summer, autumn, and winter. The orbit of the earth being elliptical, the earth must some times approach nearer to the sun than at others, and will of course take more time in moving through one part of its path than through another. Astronomers have observed that the motion of the earth is more rapid in the winter-half of its orbit than in the summer, by about seven days (*see the note to the 6th Geographical Theorem, p.* 39.); but although in the winter we are nearer to the sun than in the summer, yet if we judged by the cold experienced in winter it would appear to be further from us at this season than in summer. The explanation of this phenomenon is, that the sun's rays fall more perpendicularly on the earth in summer, and thus augment the heat; so, being transmitted more obliquely on our parallel of latitude during the winter, less heat is received, and the cold is more intense. The heat in the torrid zone does not arise from those parts of the earth being nearer to the sun, but from the rays of the sun falling more perpendicularly upon them. It might likewise be expected that, as we are less distant from the sun in the winter than in the summer, it would appear larger; but the difference of situation is so small as to make no sensible alteration to the naked eye in the sun's apparent magnitude.†

The sun is not supposed to be fixed in the centre of the earth's elliptical orbit, but in one of the foci. Let S represent the sun (*Plate* II. *Fig.* 3.) and AGFBDE the elliptical orbit of the earth. Then A is called the Perihelion, or lower apsis, being the earth's nearest distance from the sun; B is called the Aphelion, or higher apsis, being the greatest distance of the earth from the sun; and so the distance between the sun (in the focus) and the centre, is called the excentricity of the earth's orbit. If from the centre C there be erected upon the axis AB the perpendicular CE, meeting the orbit in E, and the line SE be drawn, it will represent the mean distance of the earth from the sun, being equal to half the axis AB[*], consequently SE is 95 millions of miles.[†]

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* This is not strictly true; though the variation called the nutation of the earth's axis, is scarcely perceptible in two or three years.

† The sun's diameter, as measured by the micrometer, is sensibly larger in perigee than in apogee; *i. e.* in winter than in summer. The difference as measured is 1′ 3″. See page 59.

Though the motion of the earth in its orbit be not uniform, yet it is regulated by a certain immutable law, from which it never deviates; which is that a line drawn from the centre of the sun to the centre of the earth being carried about with an angular motion, describes an elliptical area proportional to the time in which that area is described[‡], viz. if the times in which the earth moves from A to E, from E to D, and from D to B, be equal, then the areas, or spaces, ASE, SED, and DSB, will all be equal. The motion of the earth is sometimes rapid and sometimes slow in moving through equal parts of its orbit; for when the earth is at A (in the winter), the sun attracts it more strongly, and therefore the motion is quicker than any where else. On the other hand, when it is at B (in the summer), it is least affected by the sun's attraction, and consequently the motion there is slower than in any other part of its orbit, for the power of gravity decreases as the square of the distance increases [§]; besides it is obvious, from the construction of the figure, that, if the space ASE be described in the same time with the space BSD, the arc AE will be greater than the arc BD.

The phenomena of the different seasons of the year will appear plainly from the following observations. Let ABCD (*Plate* 3. *Fig*. 1.) represent the plane of the earth's annual orbit, having the sun in the focus F; and let *a b*, an imaginary line passing through the centre of the earth, be perpendicular to this plane; also let the polar axis N S of the earth make an angle of 23° 28′ with this perpendicular; then if the earth move in the direction A, B, C, D, in such a manner that N S may always remain parallel to itself, and preserve the same angle with *a b*, it will illustrate the changes of the seasons; for, suppose a line to be drawn from the centre of the sun to the centre of the earth, it is evident that the sun will be vertical to that part of the earth which is cut by this line. Now, when the earth is in Libra ♎ (*i.e.* in the spring quarter), the sun will appear in Aries ♈, and he is then said to enter this constellation. The sun will at this time be vertical to the point O, *i.e.* where the equinoctial line intersects the plane of the ecliptic. One half of the earth only can at any period receive his rays; and at this season (21st March) the boundary of light and darkness will pass exactly through the two poles N S. Each parallel of latitude must therefore have an equal quantity of light and shade; and to the inhabitants of the whole earth, the day and night will be of equal length*, *i.e.* twelve hours each. In moving from Libra ♎ to Capricorn ♑, in consequence of the polar axis preserving the same inclination to the plane of the ecliptic, the regions around the north pole N will receive more light, while those around the south pole S will receive less. On the 21st June, when the earth is in Capricorn, and the sun appears to enter Cancer, his rays will be vertical to a point situated 23° 28′ north of the equator. Hence, as one half of the earth must always be illuminated, it follows that the rays of the sun will reach to a point situated 23° 28′ beyond the north pole. This is the exact extent of the polar circles (*Def.* XVII. p. 5). Hence the inhabitants of the Arctic circle will have light, and those of the Antarctic circle will have darkness, for four-and-twenty hours: in other words, the sun will not set to the former, nor will it rise to the latter. The sun has then reached the summer solstice (*Def.* XXXI. p. 7.); and it is summer to the inhabitants of the northern, but winter to those of the southern, hemisphere. While the earth proceeds in its orbit from Capricorn ♑ to Aries ♈, the polar axis still preserves the same inclination to the plane of the ecliptic, and the north polar regions receive daily less light. On the 21st September, when the earth is in Aries, and the sun appears to be in Libra, his rays are again vertical to the point at which the plane of the ecliptic cuts the equator. The boundary of light and darkness, therefore, passes again through the two poles N S*; and for the reason just assigned, day and night will be equal, *i.e.* each will be twelve hours in length to all the inhabitants of every parallel of latitude. This is called the autumnal equinox. Between the 21st June and the 21st September, one half of the Arctic circle has been thrown into shade, and one half of the Antarctic circle has become illuminated. In proceeding from Aries ♈ to Cancer ♋, *i.e.* from the autumnal to the winter quarter, it will be observed that the sun has become vertical to a point 23° 28′ south of the equator. Hence, for the reason assigned in speaking of the summer quarter, the whole of the Antarctic circle will be illuminated, while the Arctic circle will receive no light whatever. All places in the southern hemisphere will receive the sun's rays for a proportionally longer period, and the day will appear longer than the night. These conditions are exactly reversed in the northern hemisphere: for in the same parallel of latitude, in consequence of the earth moving round its polar axis which is turned from the sun, the night will be long and the day short. The higher the latitude, the more striking will this difference become. These changes, it must be remembered, are progressive, so that the polar circles are only gradually illuminated and darkened over a period of six months, *i.e.* from the summer to the winter, or from the winter to the summer solstice.

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[*] It is demonstrated by all writers on conic sections, that a line drawn from one end of the conjugate axis of an ellipsis to the focus, is equal to half the transverse axis, *viz.* SE=CB or CA.

[†] In the figure, the elliptical form of the earth's orbit is necessarily exaggerated, in order to make the description intelligible. While the mean diameter of the earth's orbit is 190,000,000, the distance of one focus of the orbit from the other is 3,159,158 miles. See page 59.

[‡] This law was discovered by Kepler, and demonstrated by Sir Isaac Newton. See the Principia, Book III. Prop. xiii.

[§] Newton's Principia, Book III. Prop. ii.

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* See definition 30. page 7. Equinox, from *æqua*, equal, and *nox*, night.

From this explanation it will be seen that the variations in the seasons are owing, 1. to the axis of the earth preserving in all parts of its orbit, the same degree of inclination (23° 28′) to the plane of the ecliptic, and 2. to the diurnal motion of the earth around this axis. That the direction of the axis remains unchanged throughout the year, is proved by the north pole always pointing to the star in the tail of the Lesser Bear, which is thence called the *Polar Star.* Although in the summer solstice, the earth is 180,000,000 miles distant from the spot in which it was situated at the winter solstice, still the direction of the polar axis, with respect to this star, is not in the slightest degree changed—a fact which proves that the distance of the stars from the orbit of the earth must be immense.

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* The earth, as represented in *Fig.* I. *Plate* 3. in the autumnal quarter, appears to be entirely in shade, because the spectator is supposed to be viewing these changes out of the ecliptic, in the direction of the shorter axis of the ellipse. Hence, only the illuminated half of the earth is seen in the spring quarter, and only the shaded side in the autumnal quarter.

CHAPTER V.

Of the Origin of Springs and Rivers. — On Lakes, Inland Seas, and the Ocean.

SPRINGS. It is now well ascertained that springs are derived from the deposit of water which has been raised by evaporation into the atmosphere, under the influence of solar heat. The whole of the waters of the globe thus continually contribute a large amount of vapour, which is collected into clouds, and under various atmospheric conditions subsequently reaches the earth in the state of rain. Vast quantities of water are also deposited in the form of dew, and there are certain regions of the earth of vast extent which are called rainless districts, where the water is never precipitated, except in the state of dew. In mountainous countries large quantities of water are continually falling in the form of rain, owing probably to the attraction which mountains exert upon the masses of vapour. At a certain elevation, however, where an intense cold prevails, this vapour is always deposited as snow, which gradually hardens, by partial freezing and thawing, into masses of ice, forming the glaciers which are met with in the hollows and on the sides of lofty mountains. These glaciers gradually slide into the valley below, melt in the warmer atmosphere, and give rise to streams and rivers. The Arve, which flows into the Rhone near the lake of Geneva, is formed almost entirely from the melting glaciers of Mont Blanc. In countries in which so great a degree of cold does not prevail, the water deposited either as rain or dew, descends through the porous strata of the earth, such as sand, gravel, or through the wide fissures and cracks which naturally exist in chalk, limestone, and other rocks, until it reaches a stratum which is no longer porous, as a dense bed of clay or marl, and under these circumstances it is accumulated. During this descent, however, the properties of the water become materially altered. Rain-water, when collected at a distance from human habitations, is remarkably pure. It contains no saline or organic matter, and in every respect resembles that which chemists call distilled water.* The evaporation of water from rivers, seas, and lakes may be indeed regarded as a grand natural process of distillation. Water, however, happens to possess remarkably solvent powers, so that it cannot come in contact with the earth without dissolving various saline substances; and even in traversing the atmosphere, it dissolves out of it carbonic acid gas, or fixed air, which increases its solvent powers upon one of the most common constituents of the superficial strata of the earth, namely, carbonate of lime. The longer it remains in contact with the strata, the larger the quantity of saline matter which it will dissolve. When, however, the accumulation has reached a certain point, its pressure causes the strata to give way, and it then becomes a *spring*, showing itself in a small trickling stream on the surface, or collecting in any neighbouring hollow or recess. This may happen at or near the summit of the mountain, although springs in such situations are commonly small. In the mountainous regions of the Alps, small lakes are thus formed by the accumulation of the water of many springs, and from these proceed the sources of the Rhine, the Rhone, and other great rivers.† That a spring should constantly flow, it is necessary that the supply of water should be much greater than the loss; and this may happen from the aperture of escape being small compared with the quantity pent up within the adjacent strata. It is in this way that we may account for some kinds of intermitting springs, *i.e.* springs which occasionally cease to flow and suddenly burst out again. The source or reservoir may become temporarily exhausted, or be drained off in another direction. Springs are always observed to be most numerous in mountainous districts, owing to the enormous quantity of rain which falls in these regions.

INTERMITTING OR PERIODIC SPRINGS. This name is properly applied to those springs in which the flow of water is at certain periods entirely suspended. In countries where there are lofty mountains covered with snow, the phenomenon of intermission may be explained by the alternate thawing and melting of the snow and glacier-ice, according to changes of temperature. In temperate latitudes it is often observed that some springs are dry during the wet season, and flow only in dry weather. This is doubtless because the rain which falls, occupies some time in percolating through the strata of the earth. These intermitting springs are most common on the slopes of hills and mountains, while the perennial or constant springs are found at the lowest levels, the supply of water for the latter being from their situation much more abundant.

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* The water received in perfectly clean glass vessels on the summit of a house during a shower of rain in London, on a clear summer's day, after the air had been already washed by previous showers, contained ammonia, with muriatic acid in the morning, and sulphuric acid in the afternoon. There were also present in it faint traces of lime.

† In some instances, however, these elevated lakes have no visible outlet. The fissures through which the waters are discharged are then probably situated at, or near, the bottom of the lake, and the water continues to descend through the strata until it finds an outlet, in the form of a spring, on the slope of the mountain.

It is not easy to account for all the phenomena connected with intermitting springs. One of the most remarkable of these is at Paderborn in Westphalia. After having flowed for twenty-four hours, this spring entirely ceases for the space of six hours; it then returns with a loud noise in a powerful stream mixed with air. Sometimes the flow of water does not entirely cease, but the quantity of water varies at different periods:—these have been called reciprocating springs. The Giggleswick well of Yorkshire is an instance of this kind of spring. The level of the water rises and falls at intervals of ten or fifteen minutes. The water of the great Artesian wells of this metropolis is often observed to undergo considerable alterations in its level. There is no satisfactory theory to account for these variations in the flow of water. The hot Geyser springs of Iceland are instances of intermitting springs on a large scale. These probably depend on the force exerted by steam on water condensed in hollow cavities, and communicating with the surface of the earth by a syphon-like canal. This theory is supported by the fact, that the force of ejection is considerably increased by filling up the opening with heavy masses of stone. In this way the steam acquires great elastic force, and re-acts with such power as to project the water to the height of from one to two hundred feet.

When the flow of water through the earth is in any way impeded by the nature of the strata so that it cannot issue as a spring, it collects in large quantities, and may occasion dangerous accidents. What are called dykes or faults in mines, consist of veins of a hard impermeable rock, through which water cannot find its way. It there collects during many years, or perhaps during centuries, and may suddenly burst through and deluge the mine; or this accident may happen by the accidental removal of a mass of rock during the working of the mine. The fearful accident of the fall of the Rossberg mountain in Switzerland was owing to a spring, the issue of which to the surface was impeded. The water collected in a vein of clay, placed in a slanting direction, upon which the summit of the mountain rested. This stratum became so much softened that the summit slid off by its own weight, falling upon and burying a whole village with its inhabitants, and spreading the greatest desolation for many leagues around.

It was formerly supposed that springs were *veins* of water traversing the earth in particular directions; but the error of this opinion is clearly shown by the fact, that if the water be pumped out of one deep well, it will effectually dry up all the other wells for a great distance around. This proves that the sources of water in a district are directly connected. In level countries the water sometimes takes a long subterranean course between strata, collecting on those which it cannot penetrate, such as plastic clay, provided the form of the strata be such as to hold it. The strata at a great depth under London have a basin-like form, and the water is probably here accumulated in a kind of large subterranean lake; a view which is borne out by the fact, that when the deep well connected with a brewery on the south side of the Thames has been long worked, the level in the wells on the north side of the river has become depressed. This indicates a communication under the bed of the Thames, and wholly independent of that river. It has been also remarked that in certain years there has been an extraordinary and sudden depression of the water in these wells, and that without any apparent reason, they have as suddenly regained their former height. This may be accounted for by a portion of the subterranean water having found a vent elsewhere, which may have become again filled up by portions of less permeable strata.

This theory of springs will account for the fact that water may be obtained in most localities by digging or boring the earth to a certain depth. Two conditions are necessary for success:—1st, that there should be a stratum not permeable to water; and 2d, that the impermeable stratum should have a hollow form, or not be so inclined as to allow the water to flow off by its own gravity.*

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* When spring water is not procured in sufficient quantity, or of good quality, by digging, it has been the practice of late years to bore through the strata to a considerable depth. If the water have a higher temperature than common spring water, and if it rise to the surface, or above it, we have what is called an *Artesian well*, from the practice of obtaining water by this method having been first adopted in the province of Artois, in France.

In common wells, sunk in this latitude to a depth of 50, 60, or 100 feet, the temperature of spring water is generally found to correspond with the mean temperature of the climate. The water in the chalk wells at this depth around London, has a temperature of about 51°; at Brighton, it varies from 50° to 52°; at Tunbridge, it is 50°; thus nearly corresponding to the mean temperature of the climate. It has been found that the water in the wells of New York, at a depth below 40 feet, has a temperature of from 54° to 56°. The mean temperature of New York is nearly 55°.

Water obtained from a very great depth is always considerably warmer than the mean temperature of the climate. Dr. Forbes found, in his experiments, that the temperature of water in the Cornish mines gradually rose with the depth, the ratio of increase being 1° in from 45 to 50 feet. Mr. Fox ascertained, some years since, that from the Poldice mine at 1000 feet in depth, the average quantity of water pumped daily amounted to two millions of gallons, varying in temperature from 90° to 100°; *i. e.* from 40° to 50° above the mean of the climate.

Artesian wells present numerous interesting facts. In some instances there is a near approximation in the temperature of the water over very great distances. Thus the water of an Artesian well at Vienna, 200 feet deep, has a temperature of 55°; while the water of another, at Hanwell, in Middlesex, at the depth of 290 feet, has the same temperature. These places are about a thousand miles apart.

One of the most remarkable of these wells is that of Grenelle, in Paris, the depth of the water from the surface is 1794 English feet, and its temperature is 82°. The temperature of the water was found to rise 9° in the last 500 feet; that is to say, about 1° in 55 feet. In another well, that of Mondorf, in Prussia, the deepest in the world (2202 feet), the temperature of the water is 93°, indicating an increase of 1° in 54 feet.

The boring of the Artesian well of *Grenelle* was commenced in November, 1833, and it was not until February, 1841, that a supply of water was obtained. The borer suddenly fell several yards, and an immense column of water immediately sprang up, cold at first (cooled by the upper strata), but afterwards warm. The quantity of water discharged was 600 gallons per minute, and it rose to a height of 100 feet above the surface. The water from this deep well is very pure and soft, containing only 14·3 parts of saline matter in 100,000 parts. Nearly one-half of this consists of carbonate of lime, and about one-fifth of bicarbonate of potash. The Artesian water of London contains carbonate of soda. The Grenelle well must derive its supply from an enormous subterranean lake or reservoir, nearly 2000 feet below the surface of the earth. The sudden falling of the borer probably indicated its depth.

From what has been already stated it is evident, that springs must vary greatly in the quantity as well as in the quality of the water which they yield. The largest spring in Great Britain is that of *Saint Winifred's Well* in North Wales. It may be considered as the bursting out of a subterranean river; for, according to Dr. Traill, it throws up about twenty-one tons of water per minute, or 30,240 tons daily. This spring issues from a hill, which is much disturbed by numerous mineral veins. As the temperature of the water is several degrees above that of the climate, it is probable that it rises from a considerable depth.[*]

The water must rise either in consequence of its being under great pressure, or of its being derived from some very remote source placed at a much higher level.

[*] Spring water always contains air, and sometimes a large quantity of fixed air, or carbonic acid. When evaporated, it leaves a residue of saline matter, consisting chiefly of carbonate of lime, sulphate of lime, and common salt. The proportion of saline matter is from $\frac{1}{3000}$th to $\frac{1}{6000}$th part of the weight of the water. The writer lately had to examine some water which it was proposed to bring from a distance of eight miles for the supply of a populous town. Its specific gravity was 10003. It contained only 10·4 grains of saline matter in the imperial gallon. This was chiefly carbonate of lime mixed with chloride of sodium (common salt), and the proportion was $\frac{1}{6682}$nd part. It was a good wholesome water. Some of the spring waters around London yield from fifty to one hundred grains of saline matter to the imperial gallon. They contain sulphate of magnesia (Epsom salt), and are very unwholesome. In 1846, the writer had to examine some spring water supplied to our troops at Aden, on the Red Sea, which it was supposed had caused many deaths. It had a very high specific gravity and a saline taste. It contained no less than 440 grains of saline matter to the imperial gallon! This was chiefly common salt. In the deserts of Africa and Arabia, the springs are nearly all brackish, *i. e.*, they contain salt, which is abundantly diffused through the sands of the deserts, and washed out by rain or dew.

The qualities of spring water must of course vary with the locality and the nature of the soil through which the water percolates. In the eastern counties, and in Derbyshire, where chalk and limestone abound, the predominant ingredient in spring water is carbonate of lime. In districts where magnesian rocks exist, the salts of magnesia are abundant, giving the water a bitter taste. In gravelly districts, where much iron is present, the water is impregnated with iron, as at Tunbridge Wells. These are called *Chalybeate* springs, from the Chalybes, an ancient nation of Pontus, who were amongst the first workers of iron. In clay beds, where iron pyrites (a mineral compound of sulphur and iron) are found, as at Kilburn and Harrowgate, the water undergoes a chemical change by contact with this mineral, and acquires a most nauseous odour and flavour from the presence of sulphuretted hydrogen. These are called sulphureous springs.

When the saline ingredients in water are in such quantity as to give to it a perceptible taste and odour, it is called a *mineral* water.

RIVERS. The springs which issue from the fissures in the strata unite to form streams and rivulets. These descend to a lower level, meet with other streams, and the whole combine to form a river, which flows to the sea, thus rendering back to the ocean the water which had been taken up by evaporation. The number of considerable rivers which fall into the sea from different parts of the old continent, amounts to 430, and those of the new continent may be estimated, according to Dr. Traill, at 140; but this seeming disproportion is amply compensated by the vast dimensions of the latter.*

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* The flowing of rivers is entirely owing to the difference of level between the source and the outlet into the sea. The motion of a river in its current, is therefore referable to that of solids descending inclined planes, but affected by the friction of banks and other causes, owing to the free mobility which exists among particles of liquids. In the first part of its course, the current is rapid and the channel narrow; but, towards its termination, the river widens and the current becomes slow. In these cases, the river often finds its way into the sea by numerous small channels; and, as these commonly approach to the form of a triangle, or the Greek Δ, the space is called a delta. The Ganges, the Nile, and the Niger, are rivers which have large deltas: the course of the main stream having been interrupted during the progress of ages by the slow deposit of sandy and alluvial matter at the junction of the river with the sea.

The mouth of the Rio de la Plata, in South America, between Cape Saint Antonio and Maldonado is 150 miles! The Maranon or Amazon is, however, in its course, and in its volume of water, the most stupendous river in the new world. At more than 1000 miles from its mouth, the depth of its bed was found by Condamine to be 620 feet, *i. e.*, more than 100 feet below the level of the Atlantic; so that the upper portion of the river only can flow to the ocean. The tides are perceptible for 600 miles up the river. It falls 1235 feet in 3000 miles. This is about five inches per mile as its mean declivity; but in the lower part of its course the fall is considerably less than this.

The force of the currents of these mighty rivers where they empty themselves into the ocean, may be estimated from the following facts: — The current of the Rio de la Plata, according to Rennell, preserves an easterly direction, with a velocity of a mile an hour, and a breadth of more than 800 miles, at a distance of not less than 600 miles from the mouth of the river. Lieut.-Col. Sabine crossed the current of the Amazon at a distance of upwards of 300 miles from the mouth, still preserving a velocity of nearly three miles an hour, its original direction being but little altered, and the fresh water but partially mixed with that of the ocean over which it flows. The distinction between the river current and the sea water, was clearly distinguishable over a breadth of 100 miles!

The following account of Captain Hodgson's tour to discover the sources of the immense rivers Ganges, Jumna, and Bhagirutta, which take their rise in the Himalaya Mountains, is highly interesting. Captain Hodgson left Reital (a village in 30° 48′ N.) on the 21st of

Rivers are not extensive in proportion to the elevation of their sources, but to the number and size of the streams which flow into them. Thus, the large river Volga rises at an elevation of about 550 feet, and falls into the Caspian, after running a course of 2400 miles. As the Caspian Sea is not more than 83 feet below the level of the Black Sea, the total fall in this immense distance amounts to only 633 feet, or but little more than three inches in a mile. The following rivers rise at various elevations above

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May, 1817. On the 31st he descended to the bed of the river, and saw the Ganges issue from under a very low arch at the foot of the grand snow bed. The river was bounded on the right and left by high rocks and snow, but in front, over the *débouché*, the mass of snow was perpendicular; and from the bed of the stream to the summit, the thickness was estimated at little less than 300 feet of solid frozen snow, probably the accumulation of ages, as it was in layers of several feet thick, each seemingly the remains of a fall of a separate year.

From the brow of this curious wall of snow, and immediately above the outlet of the stream, large and hoary icicles depended. The height of the arch of snow was barely sufficient to let the stream flow under it. Blocks of snow were falling on all sides, and there was little time to do more than measure the size of the stream, the mean breadth of which was 27 feet, and its depth varied from 9 to 18 inches. Captain Hodgson believes this to be the first appearance in daylight of the celebrated Ganges. The height of the halting-place, near which the Ganges issues from under the great snow bed, is calculated to be 12,914 feet above the level of the sea. The height of the Bhagirutta source of this river is, according to recent observations, no less than 13,672 feet above the level of the sea. The source of the Ganges is the loftiest in the world.

At a distance of 1800 miles from its mouth, the Ganges is only 800 feet above the sea-level; and to fall from this level, it is calculated that it requires a period of more than a month.

At Jumnoutri, the visible source of the river Jumna, the snow which covers and conceals the stream is about 60 yards wide, and is bounded on the right and left by precipices of granite 40½ feet thick, which have fallen from the precipices above. Captain Hodgson was able to measure the thickness of the bed of snow over the stream very accurately, by means of a plumb-line let down through one of the holes in it, which are caused by the steam of a great number of boiling springs at the border of the Jumna. The head of the Jumna is in the S. W. side of the grand Himalaya range; differing from the Ganges, inasmuch as that river has the upper part of its course within the Himalaya, flowing from S. E. to N. W.; and it is only from Sookie, where it pierces through the Himalaya, that it assumes a course of about 20 S. W. The mean latitude of the hot springs of Jumnoutri appears to be 30° 58′.

After descending into the bed of the Bhagirutta, that river was also traced nearly to its source; the glen through which it runs is deeper and darker, and the precipices on either side far more lofty than those forming the bed of the Jumna: the rock in the neighbourhood of its source was granite, and contained black tourmaline.

the sea-level: — The Danube, 2850 feet; the Elbe, 4500 feet; the Rhine, 7650 feet; and the Rhone, 5500 feet.

The mean velocity of rivers is estimated at from 3 to 4 feet in a second. It is determined by measuring the motion of solid bodies which are of about equal specific gravity with water. A very rapid stream rarely flows more than 13·3 feet in a second. This is about equal to nine miles in an hour. The central current of the Thames flows at a mean rate of from 4 to 5 miles in an hour. A fall of one inch per mile in a smooth straight channel gives a velocity of three miles per hour. The maximum velocity of rivers is to the mean velocity as 5 to 4 nearly.

INUNDATIONS. — Rivers which run through low flat districts and terminate in deltas, are subject to inundations, whereby large tracts of country are covered with water. In some parts of the world these inundations are periodical, and depend upon the fall of an enormous quantity of rain within a short period. This is the case with the Nile, the Ganges, and the Mississippi. The accumulation of water is so vast, that it cannot be discharged through the ordinary channel. In some instances these inundations are attended with benefit, as the supply of water tends to fertilize large tracts of arid soil; and care is taken to avoid those accidents which might otherwise occur. The inundation of the Mississippi occurs in spring, towards the part where it pours its waters into the Gulf of Mexico: it is then no longer a river, but a kind of muddy sea, bearing on its surface enormous masses of wood, washed from its banks. These logs, mixed with mud and sand, tend to fill up the delta. According to M. de Beaumont, the promontory at the mouth of this river is lengthened yearly to the extent of 1150 feet by the constant addition of vegetable and earthy matter.

Some of the rivers of Europe are liable to destructive inundations after the long-continued fall of rain. The Rhone, the Po, and the Arno, have thus risen above their banks, and have laid waste large tracts of country, causing an immense destruction of life and property. Florence and Pisa have only recently suffered from a great inundation of the Arno. These events are unusual; and, as no preparation is made against such occurrences, their effects are for a long time seriously felt. In mountainous countries, extensive inundations often occur from the sudden and rapid melting of the snows.

Philosophers have endeavoured to calculate the proportion of water evaporated, and to compare this with the quantity returned to the ocean by rivers. It is obvious that nothing more than an approximation can here be obtained. Dr. Halley, during his residence at St. Helena, estimated from his experiments that *ten square inches* of the surface of the sea yielded *one cubic* inch, or 252½ grains of water by evaporation in every day of twelve hours; and on this datum a square mile of the ocean would yield 6914 tuns of water in the same time. He further calculated that the quantity evaporated from the surface of the Mediterranean on a summer's day, was not less than 5280 millions of tuns!

This enormous amount of water, thus carried into the atmosphere in the form of invisible vapour, is quite sufficient to account for the formation of springs and rivers by its deposit as rain or dew. It has been supposed that the amount contributed by rivers, would not be sufficient to make up the loss thus occasioned by evaporation. Halley calculated that not more than 1827 millions of tuns of water again flowed into the Mediterranean by the rivers which emptied themselves into this sea; and although a vast current sets in from the Atlantic, this, added to the supply from the rivers, would still fall far short of the quantity evaporated. But the Mediterranean has scarcely altered its level for the last 2000 years, as the Roman villas, the ruins of which are still standing on the Bay of Baiæ, prove; if any difference has taken place, it has been rather by increase than decrease. Further, the Mediterranean does not become more salt than the Atlantic in the same parallel of latitude. In making this comparison, it has not been considered that a very large portion of the water which is raised into the atmosphere, is again returned to the sea itself.* The mean annual fall of rain on the globe is estimated at 105,614 cubic miles: if this precipitation take place upon land and sea in proportion to their respective surfaces, then the quantity which falls on the sea will be 67,343 cubic miles, and on the land 38,271 cubic miles of water. Out of this it is calculated that two thirds are expended in irrigating the soil, or in supporting vegetable life, and pass again into the atmosphere by evaporation, so that no more than 12,757 cubic miles will annually reach the ocean by rivers.† All the

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* The Mediterranean is 2350 miles in length. Its breadth varies from 100 to 650 miles, and its area is equal to 1,000,000 square miles.

† This is the estimate given by Dr. Traill; but Professor Berghaus has arrived at a different result. According to this authority, the mean annual fall of rain within the tropics is about 8·5 feet; in the temperate zones, 3·05; and in the frigid zones, 1·25 feet. The area of the torrid zone may be represented by 4 nearly; that of the sum of the two temperate zones by 5; and that of the two frigid zones by 1. Now, proportioning the fall to these numbers representing the respective surfaces, the general mean for the whole earth will be *five feet* of depth of fall very nearly. This mean depth would give 186,240 cubic imperial miles of water, or 760,000,000,000,000 of tuns of water, for the total annual fall of rain on the surface of the globe!

According to Mr Dalton, the quantity of rain which falls in England is 36 inches a year. Of this, 13 inches flow off to the sea by rivers, and the remaining 23 are raised again from the ground by evaporation. The researches yet made, render it, however, probable that there is a compensation between the amount of water raised by evaporation, and that which is again deposited on the earth and sea under the form of rain and dew. If any difference appear, it is probably owing to the difficulty of obtaining accurate data for solving the question.

LAKES. By the term lake is understood a large accumulation of water, derived from one or more rivers, or from the meeting of a number of small streams. Lakes are most frequently met with in rocky or mountainous countries. When they exist on plains they are generally shallow; and in tropical countries, if of small extent, the bed becomes dry during the hot season. The depth of a lake is commonly determined by the slope of the mountains forming its boundary, and thus some of the deepest lakes are bounded by the most abrupt precipices. In general the water resembles that of the river; but when the lake has no outlet, and the soil is saline, the waters become salt. This is the case with the Lake Asphaltites, or the Dead Sea in Palestine. The waters of this lake contain a greater proportion of salt than those of any other lake or sea in the world.* It is remarkably deep compared with its extent. It has a length of sixty miles, with an average width of ten miles, and is about fifty miles distant from the coast of the Mediterranean. Its surface is depressed, according to the measurement of Lieut. Symonds, in 1841, no less than 1312·2 feet below the level of this sea! It was sounded a few years since by Mr. Moore, but no bottom was found at the great depth of 220 feet! If we add to this its depression, below the level the Mediterranean, it is obvious that there is in Palestine, ly fifty miles distant from the coast, an enormous chasm in e earth upwards of 3500 feet in depth. The level of its sur-ce is probably the lowest on the globe. The principal river hich flows into it, is the Jordan, the waters of which are not ore saline than those of other rivers; and the great saltness

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inches of water are, of course, supplied by evaporation from the sea, d are carried back to the land through the atmosphere.

* The specific gravity of the water is 1·21. It contains 26 per cent. saline matter, more than one half of which is common salt. Sea water ely contains more than from 3 to 5 per cent of saline matter. Com-m water boils at 212°: the water of the Dead Sea, in consequence of e large proportion of salt contained in it, does not boil under a tempe-ure of 222°.

of the lake must be ascribed to the large quantity of rock salt which exists in and around its eastern shores. The Lake of Tiberias is 329 feet below the level of the Mediterranean. There can be no communication between these lakes and the sea, or the whole of that part of Palestine would be flooded.*

The most important lakes in the world are the great fresh-water lakes of North America. Lake Superior is 380 miles long, 161 miles broad, and its surface is 672 feet above the level of the Atlantic. Its average depth is 900 feet; but in some parts it has been sounded to the depth of 1200 feet. It covers an area of about 32,000 square miles. Its bottom is 300 feet below the level of the Atlantic ocean! These enormous masses of water must be regarded as *inland seas.* The water is saline, but not salt like that of the sea. It differs but little in chemical properties from the river water which flows through them. It was long since remarked that all lakes from which rivers derive their origin, or which fall into the course of rivers, are not saline like the water of the sea; while those on the contrary which receive rivers without other rivers issuing from them, are saline. This view is borne out by observations made on the great central basin of Europe and Asia, in which are situated some remarkable salt lakes or inland seas. This vast basin, into which water is poured by a large number of rivers, but from which no water again issues into any of the surrounding seas, reaches nearly from the Baltic to the Yellow Sea, and from the Persian Gulf to the White Sea. The Volga, which carries off as much water as the Mediterranean receives from all the European rivers, flows into it, discharging itself into the Caspian Sea or lake, from which there is no outlet. This sea has a length of 700 miles, a breadth of 210 miles, and a depth of upwards of 400 fathoms: in some places 2700 feet of line failed to reach the bottom. Its area is equal to 147,000 square miles. The waters are as salt as those of the Atlantic or Pacific.* The sea or lake of Aral is also extremely salt. There are numerous other salt lakes in this basin which, are recipients of rivers, and have no outlets. The saltness of the water is ascribed to the effect of evaporation, slowly leading to its concentration; for the chloride of sodium (common salt) is a constituent of all river water, but it is especially abundant in the waters of those rivers which flow through the vast sandy plains of central Asia. The waters of the sea of Aral are found to be much salter than those of the Atlantic. It is worthy of remark, however, that while the Caspian is only 83·6 feet below the level of the Black Sea, there are great salt marshes which extend between the two, rendering it probable that they have been at one time united. The Caspian and the Aral contain the sturgeon, the herring, and the seal, with the deep-sea fish found in the ocean — a kind of zoological evidence of a former union with the great mass of waters that cover the globe.

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* The highest water level in the world is probably Lake Sir-i-Kol, in central Asia, the source of the river Oxus. According to Lieut. Wood, this is situated at an elevation of 15,600 feet above the sea. Between this level and that of the Dead Sea is a space of no less than 16,912 feet.

Some inland gulfs are remarkably deep. One arm of the Red Sea — the Gulf of Akabah, was found by Lieut. Wellsted to be 1200 feet in depth at a distance of only 50 yards from the shore.

The level of the water at the Isthmus of Suez, near its northern extremity, is, at various periods of the day, from twenty-five to thirty-two feet above the level of the Mediterranean. This is probably due to the narrowness of the straits of Bab-el-Mandeb and the great length of the sea, circumstances which tend to prevent the egress of water carried into it by the currents of the Indian ocean.

The difference in the levels of the Atlantic and Pacific Oceans, on either side of the Isthmus of Darien, has been much exaggerated. According to the most accurate measurements over a distance of 64 miles, the level of the Pacific is about 3·6 feet above that of the Atlantic; and it appears that at different hours of the day, according to the tides, one sea is higher than the other.

Lake Baikal, which is not in this basin, is a considerable fresh-water lake, being 360 miles long by 40 broad. It discharges itself into one of the branches of the Yenisei.

THE OCEAN. The whole area of the waters of the ocean is estimated at 144,000,000 square miles. The oceanic water is strongly saline, and it owes its bitter taste to its containing salts of magnesia.† By the effect of winds producing waves, currents, and tides, the waters are in continual motion.*

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* According to recent calculations, nearly one half of the whole running water of Europe falls into the Black and Caspian Seas; which is the more remarkable, as the one is an inland sea, situated in the interior of the continent, and the other, a completely enclosed inland lake.

† The specific gravity of sea water is influenced partly by its temperature and partly by the quantity of saline matter contained in it. A portion taken from the surface of the Atlantic, in the Gulf of Guinea, had a sp. gr. of 1·028. It yielded on evaporation 3·5 parts of saline matter per cent — two-thirds of which were common salt. The proportion of saline matter contained in sea water increases as we approach the equator; but the difference in quantity in north latitude, 80° and 14°, was not more than 0·46 per cent. Some water drawn up by Captain Wauchope from a

It is probable that in some parts of the deep sea there are strong currents like those which are met with on the surface.† The *colour* of the sea when of great depth is a rich

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depth of nearly 4000 feet in the Gulf of Guinea, 100 miles from the coast, had a specific gravity of 1·03, and it yielded 4·5 per cent. of saline matter. The surface water in this case contained less than that found at a great depth; but it is remarkable, as showing very great uniformity of composition in the waters of the ocean, that those peculiar elements, iodine and bromine, were discovered in the deep sea water.

In Captain Ross's more recent observations in his Antarctic voyage, it was found that water, taken at a depth of 4000 feet, scarcely differed in the specific gravity, and therefore in the proportion of saline matter, from that taken at the surface. Making due allowance for temperature, it was as nearly as possible the same.

Many speculations have arisen as to the cause of the *saltness* of the sea. One hypothesis assumes that the water of the ocean was originally fresh, and became salt by dissolving salt rocks at its bottom. Dr. Halley thought that the salt was slowly carried into the sea by rivers, and left there by evaporation: but neither view is satisfactory. We have the clearest evidence, from geological observations, that the sea has once covered the land; and it is probable that the waters then in great part acquired their saline contents. Common salt is the most abundant constituent of sea water, and with it is found much more abundantly on the earth than the other saline substances with which it is mixed; it is just as soluble in cold water as in hot. Hence, all rivers certainly carry a large proportion of salt into the sea, and but little is again lost by evaporation. When sea water freezes, the pure water separates in solid blocks of ice, while the salt is left in a state of strong brine. Some northern nations obtain their salt from sea water by this natural process. Loose, or porous ice, found in the Arctic seas is, however, generally found to contain a quantity of salt water locked up in its interstices.

* Various statements have been published respecting the height of *waves* in the open sea. Captain Ross recently made some calculations on their height in the South Atlantic (lat. 31° 20′ S., and long 0). There had been a south-westerly breeze the preceding day, amounting to a moderate gale, and the ship ran into a heavy swell. The results of several experiments gave 22 feet for the entire height of the waves, or 11 feet above the mean level of the ocean; the velocity of the undulations was at the rate of 89 miles per hour, and the interval between each wave was 1910 feet.

† CURRENTS. — According to Rennel, there are two kinds of currents; the *drift*, or superficial current, which depends on the action of prevalent winds, the velocity of which is not greater than ten or twelve miles a day, and the *stream* current, which may be regarded as an immense oceanic river, two or three hundred miles in breadth, extending to a considerable depth, and moving with an average velocity of from 60 to 120 miles a day! The temperature varies according to the climate in which the *cur-*

blue: this is especially remarkable on a calm day in the

rent has its origin. These currents flow over an almost incredible space. Thus, the water of the Indian Ocean, which washes the shores of Arabia and Southern Africa, is carried round the Cape of Good Hope, and through the Atlantic to the shores of South and North America, the Azores, and even the coasts of Europe. The Gulf stream, which issues from the Gulf of Mexico, reaches to the west of the Azores, traversing in its course twenty degrees of latitude, and passing over a distance of upwards of 3000 miles. Its breadth in the Bahama channel is fifteen leagues. Rennel calculates that it traverses this distance in 78 days, at an average velocity of 38 miles per day. At the end of the Gulf of Florida its progress is like that of a torrent, being at the rate of 120 miles per day. The water of the current is here of a dark indigo-blue colour, and the line of separation between it and the waters of the Atlantic is said to be plainly visible for hundreds of miles. Its maximum temperature is about 9° above that of the ocean. Its influence is alleged to be felt in Norway, and even on the shores of Spitzbergen. Hence the fruit and seeds of trees belonging to the torrid zone of America are occasionally thrown on the shores of Ireland, the Hebrides, and Norway. Before the discovery of America by Columbus, towards the end of the fifteenth century, two corpses, the features of which indicated a race of unknown men, were thrown on the coast of the Azores. Cargoes of vessels wrecked on the coast of Africa, have by the same means reached the Norwegian coast.

Where the Gulf stream meets with the great Southern Atlantic current in the middle of the Atlantic, the sea is covered with a weed of a bright green colour (Sargasso). According to Humboldt, the central space of the Atlantic covered by this weed is equal to an area of 260,000 square miles! It was here seen by Columbus in September, 1492. The weed is carried onwards by the Gulf stream, giving the sea a grassy-green colour.

While this current tends to warm cold climates, there is a great Arctic current issuing from under the ice in high latitudes, which flows southwards, enters at a great depth into the Caribbean Sea, thus replacing the warm water carried out by the Gulf stream, and tending to cool the hot regions of central America. The temperature of the water of the Caribbean Sea at a slight depth is below the mean temperature of the air, and as cold as that which exists at a similar depth off the shores of Spitzbergen. At a depth of 1440 feet the Caribbean water had a temperature of 48°, while that of the surface was 85°. These great oceanic currents, therefore, tend to equalize the temperature of the globe.

It is this Arctic current which brings down the icebergs and icefields from the North Polar regions into southern latitudes. Scoresby counted 500 icebergs setting out on the Arctic current at one time. They have been found north of the equator in the parallel of 40°, and south of the equator in the parallel of 35°.

ICEFIELDS have been encountered a hundred miles in length, with an average breadth of fifty miles, and rising out of the water to a height of from four to six feet.

Mediterranean*, and it is very probable that the colour is nothing more than that of a large column of clear water. When the sea is comparatively shallow, the colour is green. This is considered to be due to the yellow colour reflected by the sandy bottom mingling with the natural blue tint of the water. It was observed by Captain Ross that the sea around large icebergs, or fields of ice, commonly had a dirty brownish colour, owing to myriads of ferruginous animalcula which swarmed around them. In other places it was of a deep blue colour. This served as a kind of indication of their approach to ice.

The bottom of the sea is as irregular as the surface of the land, a fact established by the use of the plumb-line. The sea around our own coast has an average depth of 120 feet; but in some parts of the British Channel it reaches 200 feet. Around the coast of Scotland its depth is 360 feet, and on the western coast of Ireland it shelves off very precipitously towards the Atlantic, to the depth of 2000 feet. The Straits

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Icebergs, which are probably detached glaciers of the circumpolar regions, are sometimes of enormous dimensions, attaining a height of from 100 to 200 feet above the level of the water, and having a length of three-quarters of a mile, and an area of two or three miles: — they form, in fact, ice-islands. In order to comprehend their enormous dimensions, it must be remembered that from the difference in the specific gravity of sea water and ice, nearly *nine-tenths* of the mass of floating ice are below the level of the sea! This will explain why icebergs have been observed to be aground in a sea *six hundred feet* in depth. These ice islands, or mountains, thus transported by currents, dissolve in the warm sea water of low latitudes, and tend to produce an equilibrium of temperature. Their influence in this respect may be appreciated from the fact that the water is rendered perceptibly colder to a distance of forty or fifty miles around them, and in their immediate vicinity the water has sunk in temperature from 51° to 43°. Henceall winds that blow over them are exceedingly cold. From their enormous masses they have often been mistaken for fixed islands, and they yearly give rise to numerous fatal accidents at sea. Captain Sir J. C. Ross states that in February, 1842, he met with an iceberg in lat. 70° S. and long. 173° W., which had a diameter of four miles. He inferred from his observations that it was drifting southwards at the rate of one mile per diem. The great barrier of ice which intercepted his further progress to the South Pole in lat. 78° 15′, was 180 feet above the level of the sea, 1000 feet in thickness (depth), and 450 miles in length!

* In a storm the writer has observed the waters of the Mediterranean to assume the colour of ink; on a bright summer's day, they have the tint of ultramarine

of Gibraltar present a remarkable instance of inequality. In the longitude of Cape Trafalgar, on the Atlantic side of the Straits, there is a depth of 360 feet. A short distance within the Straits the depth is 6000 feet, and soon after no bottom can be discovered by the plumb-line. It would thus appear that there is here, within a very short distance, a submarine precipice nearly 6000 feet in perpendicular depth! Many of the islands scattered over the ocean, as the Canaries, Ascension, Saint Helena, Bourbon, Mauritius, and Kerguelen's Land, from the vast depth of the sea around them, can only be regarded as the highest peaks of enormous submarine mountains. They are for the most part volcanic. This great inequality of the bed of the ocean has been strikingly proved by the numerous observations on its depth taken by Sir James Clark Ross, in his late Antarctic expedition. In the Antarctic Ocean, lat. 72° S. and long. 176° E., the sea was found to be 1380 feet deep; at less than a mile distant from this spot soundings were obtained at 1044 feet. During one day's sailing, the depth was found to be at 4 A.M. 1020 feet, at 8 A.M. 1260 feet, and at 12 A.M. 1620 feet.

The submarine precipice at the entrance of the Straits of Gibraltar shows an enormous difference in the depth of the sea; but a more remarkable instance of this inequality of level was ascertained by Sir J. C. Ross in the South Atlantic Ocean. At one spot the bottom was reached at rather more than 14,000 feet; within less than 300 miles of this spot no soundings could be obtained at upwards of 27,000 feet, thus making a difference of level of 13,000 feet, which is equal to the height of the Peak of Teneriffe. The bed of the sea therefore is proved to be as irregular as the surface of the land, and there are often considerable differences of level within comparatively short distances. It is covered by submarine hills and mountains, abounding in coral and shell-fish, masses of which are often raised by the deep sea lead. The deep recesses of the ocean are thus proved to abound in animal life. Captain Ross drew up in lat. 63° S. and long. 55° W., from a depth of 1620 feet, no less than *fifty-two* varieties of minute siliceous shell-fish; and from a depth of 1380 feet the lead brought up a crustaceous animal (the *nymphon gracile*), which is common in the North Polar seas. The temperature of the water at this depth was found to be 34° 6′, *i.e.* only 2° above freezing, and yet this was not incompatible with animal life.* According to the observations of Mr. Beale, the sperm whale descends to the depth of 4000 feet.

There is great reason to believe that the coral worm must work upwards from these submarine hills and mountains, and it is not improbable that they form also the basis of submarine volcanoes.

Nothing is known concerning the absolute *depth* of the ocean. It has been sounded in various places, and in some instances at great depths, without the discovery of any bottom. In 1829 Captain Foster found no bottom in the sea off Cape Horn, at a depth of 5400 feet; *i.e.* rather more than a mile. No bottom has been found in the Gulf of Guinea 100 miles from the coast at a depth of 4000 feet. Among the deepest measurements yet recorded are those which were made in the late English and French expeditions to the South Pole. The officers of the French ship Venus found no bottom in the Pacific, 1200 miles south-west of Cape Horn, at a depth of 12,420 feet. The observations recently made by Captain Sir J. C. Ross, over a wide space in the Atlantic and Pacific Oceans, are of the most extensive and accurate kind. In April, 1841, in lat. 52° S. and 136° E., about 600 miles south of Van Diemen's Land, the sea was found to have a depth of 9240 feet. The weight lowered was 336 pounds, and it struck ground at this enormous depth (nearly the height of Mount Etna) in 24 minutes and 29 seconds. The boat was kept moored to the bottom by means of the weight, in order to ascertain if there was any deep current which affected it; but it was not perceptible. The line was then cut, not being sufficiently strong to draw the weight up again. On the 3d of January, 1840, in lat. 27° S. and long. 17° W. (in the middle of the South Atlantic, and about 1000 miles from the coast of South America), soundings were obtained at a depth of 14,550 feet; a depression of the bed of the ocean beneath its surface very little short of the elevation of Mont Blanc above it. In the southern ocean, just within the Antarctic Circle, lat. 68° S. and 12° W., no bottom was found at a depth of 24,000 feet; but the most remarkable of all these observations was that made in the South Atlantic on the 3d of June, 1843, in lat. 15° S. and long. 23° W., in a calm and smooth sea. No bottom was found with 4600 fathoms of line, or 27,600 feet, a depression equal to the height of the loftiest mountains in the world. This is the greatest depth to which the ocean has been actually fathomed.* The depth of the open Atlantic is probably not less than 26,000 feet — about five miles: the maximum depth has been calculated by Whewell from tidal undulations at 47,500 feet, or *nine* miles.† Such has been ascertained with respect to the deep sea by these soundings, namely, that its temperature over the whole ocean is remarkably uniform. At a depth of 3000 feet the temperature of the waters of the ocean is at or near 39° in spots far removed from each other. Between this depth and the surface there is great variation, but below this the temperature was found by Captain Ross, in fathoming to the depth of

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* The heavy mass of lead employed in these soundings is covered beneath with a thick layer of tallow, so that the substances which it touches at the bottom of the sea adhere to it and are brought up with it. It is often lowered for many thousand feet, and comes up with the soft layer of tallow free from any mark or indentation. The volcanic nature of the Antarctic land discovered by Captain Ross was indicated by sinking the lead, some miles from the shore, to the depth of 990 feet. It brought up several small black stones, which were evidently of volcanic origin, and had probably been thrown out as lava by the great Antarctic volcanoes, many centuries since!

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* Some of these fathomings are represented in the Comparative Section of the Earth and Sea. (See plate viii.)

† There is what appears to be a popular error respecting this method of determining the depth of the sea. It is commonly said that the density of the water would become so increased by the superincumbent pressure, that the weight would be buoyed up, and could never reach beyond a comparatively slight depth! Some nautical men of experience actually believe that at a certain depth in the ocean, lead will float. This alleged compressibility of water is wholly inconsistent with our knowledge of its properties. According to the most experienced observers, water suffers only a condensation of ·0000496 of its bulk for every atmosphere of pressure, a quantity which can scarcely be appreciated. It is calculated that it would require a depth of no less than *ninety-three miles* in order that water should become doubled in its density, or reduced to half its bulk by superincumbent pressure! As no sounding has gone beyond *five miles*, and the specific gravity of lead is *eleven times* as great as that of water, it is clear from this, if not from actual observation, that a heavy mass of this metal cannot possibly be rendered buoyant in the way supposed. Sir J. C. Ross found that 9240 feet of line ran out in 24 minutes, with a weight of 336 pounds attached to it. The first 600 feet of line ran out in 36 seconds, and the last in about two minutes, from the increased friction. Even if the sea were ninety miles in depth, the metal would be about five times as heavy, bulk for bulk, as the lowest stratum of water with which it was in contact! To suppose, therefore, that there is any accessible part of the sea where iron or lead would float, is entirely opposed to our knowledge of the great incondensability of water under pressure. A depth of a mile would give a pressure of 165 atmospheres. The condensation of water at one mile, as ascertained by submitting it to high pressure, would therefore be (·0000496 × 165) only ·008 of the bulk, and at five miles, ·04, or one twenty-fifth part! It is alleged that water undergoes a *greater* degree of condensation than this at higher pressures: but no facts are adduced in support of this statement. The theory of the hydraulic press, the action of which is based on the *in*condensability of water, is decidedly adverse to it. Water, it is well known, may be even forced, in the attempt to condense it, through the pores of thick copper and gold, as in the famous Florentine experiment. Wood, deprived

of air, has a specific gravity of 1·5; and so far as density is concerned, and irrespective of the effect of submarine currents, even this substance would sink to the depths of the sea as far as they have yet been fathomed. Admitting that the degree of condensation by pressure is much greater than that commonly assigned by philosophers, still this would not materially affect the practical results. The writer has seen it stated, but he does not know that the statement was based on experiment, that sea water at a depth of 1000 fathoms undergoes a condensation of one-twentieth of its bulk. Even if this were admitted, it would require a depth of 20,000 fathoms, or 23 miles, in order that its density should be doubled!

Another objection has been taken to the determination of the depth of the sea from these soundings, namely, that the currents of the ocean may cause the weight to drift from the perpendicular. These currents undoubtedly exist in many parts of the deep sea; but the plan adopted by Captain Ross to obviate this objection must show, that it could not apply to the soundings taken by him,—the line with the weight having been attached to a boat on the calm sea. If the supposed deep current had possessed such power as to carry a mass of lead weighing upwards of 300 pounds so far out of the perpendicular as materially to affect the calculation of the depth, it is obvious that it would have caused the boat to drift, independently of any superficial current; and this would have been indicated by its moving rapidly from the spot. As there was no perceptible motion in the boat in the 24 minutes during which the experiment lasted, it is clear that in this case the line could not have deviated to any great extent from the perpendicular by the drifting of the weight. The irrelevancy of this objection will also be apparent from the fact that the line and weight were in the condition of a pendulum upwards of 9000 feet in length! With such an enormous radius, the weight must necessarily be drifted to a considerable distance in the deep sea, in order to raise it out of the perpendicular only to the height of one foot. The line being small compared with the weight, and presenting but a very slight surface to any horizontal currents of water, cannot be supposed to be carried to any material extent from the perpendicular, since the force of gravitation would be always acting upon the lead and tending to keep it tense, even, although, on hydrostatic principles, the water would buoy it up more than air. The loss of weight from this buoyancy would not be more than 30 pounds in a mass of lead weighing 336 pounds.

The presence of saline matter in the water does not render it more compressible; and observation of its specific gravity when drawn up from great depths (3600 feet) shows that in this respect it scarcely differs from the surface water; its density (1·027) is only 1–33d greater than that of distilled water.

6000 feet, to be about the same.* From his observations he considers that the influence of the sun's heat is felt as low down in the ocean as 2700 feet. The surface temperature varies considerably according to latitude :—in the equatorial seas it ranges from 70° to 80°, and in the polar seas it is at or below the freezing point.†

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* The following Table represents the temperature of the sea at different depths and in different latitudes.

Depth of the Sea.	Lat. 66° S. Long. 19° W.	Lat. 55° S. Long. 54° W.	Lat. 56° S. Long. 6° W.	Lat. 33° S. Long. 166° E.	Lat. 60° S. Long. 131° W.	Lat. 70° S. Long. 174° W.	Lat. 67. S.
Fathoms	*Temp.*	*Temp.*	*Temp.*	*Temp.*	*Temp.*	*Temp.*	*Temp.*
1000	39·5°	39·5°					
750	39·4	39·3		40·4°			
600	38·7	39·4	39·0°	42·7	40·5°	37·6°	38·0°
450		39·6	37·8	45·6	39·5	35·8	37·5
300	35·5	39·6	36·8	49·5	38	35	35·5
150	33	40	35·2		37	32·1	34·2
Surface	30·8 ‡	40	33·5	59·7 §	35	28	33

‡ No bottom at 4000 fathoms.
§ No bottom at 750 fathoms, 270 miles off the north end of New Zealand.

† The depth of the sea has a great influence on the temperature of the surface. In shallow water the temperature is, *cæteris paribus*, lower. In the deep sea it is more uniform. Dr. Davy found on approaching the land off the Cape of Good Hope, that the temperature of the water became reduced by 2°; and it has been repeatedly observed that over a submarine bank it is lower than in the open ocean. This fact may serve to indicate the approach to land in thick and hazy weather, when there has been no opportunity of taking observations. In the Caribbean Sea, while the surface of the water had a temperature of 85°, at a depth of 240 fathoms it was found to be as low as 48°. The great Arctic current here sets into the sea under the Gulf stream. *Cæteris paribus* all inland seas have a higher temperature than the open ocean under equal parallels of latitude.

From the researches of Humboldt, it would appear that the zone of greatest warmth in the waters of the ocean, is on the north side of the equator, in about 3° north latitude. This part of the Atlantic is free from currents, and the heat becomes concentrated. The surface water of the Pacific Ocean in the equatorial region is warmer than that of the Atlantic. Over more than 50° of longitude it was found to have a uniform temperature of about 84·74°.

The temperature of the water at the bottom of deep lakes does not materially vary from that of the deep sea. Saussure made a most complete examination of this subject on all the lakes of Switzerland. Two of the deepest of the Swiss lakes are those of Geneva and Lucerne. The surface water of the lake of Geneva, examined during a cold season, was 41°, and at the depth of 1000 feet, the water had a temperature of 42°. In

Great as the assumed depth of the sea may appear to be, it dwindles to a mere film compared with the mass of the earth. Thus nine miles would represent only 1-885th part of the earth's mean diameter, and in a globe of thirty-six inches this would be equivalent to the thickness of 1-25th part of an inch. The greatest depth to which our soundings have yet extended would therefore be represented only by the 1-50th of an inch upon such a globe! (For a comparative view of the depth of the ocean see Plate VIII.)

CHAPTER VI.

Of the Flux and Reflux of the Tides.

A TIDE is that motion of the water in the seas and rivers, by which they are found to rise and fall in a regular succession; and this flowing and ebbing is caused by the attraction of the sun and moon.*

Suppose the earth to be entirely covered by a fluid as A, B, Z, C, D, Q, N (*Plate* III. *Figure* 2.), and the action of the sun and moon to have no effect upon it, then it is evident that all the particles, being equally attracted towards the centre O of the earth, would form an exact spherical surface; except, that by the revolution of the earth on its axis N S, the attraction from B towards O, and from Q towards O, would be a little diminished by the centrifugal force. Let the moon at M now exert her influence upon the water; then because the power of attraction diminishes as the square of the dis-

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the lake of Lucerne (650 feet), while the surface temperature was 68°, that of the water at the bottom was 41·5°, presenting the greatest difference among all the observations. The highest temperature observed was at the bottom of the lake of Bienne, 44°, the depth being 235 feet. This has been found to be the temperature of sea water under the equator, at the depth of 2400 feet. The lowest temperature observed in these lakes was in Lake Constance, at the depth of 400 feet, the temperature of the water being 40°. The extreme range of temperature in the water of these deep lakes was only about 4°.

* This was known to the ancients: Pliny expressly says that the cause of the ebb and flow is in the sun, which attracts the waters of the ocean, and that they also rise in proportion to the proximity of the moon to the earth. Dr. HUTTON's *Math. Dictionary*, word Tides.

tance increases, those parts will be the most attracted which are the nearest to the moon, and their tendency towards O will be diminished: the waters at Z, B, and C, will therefore rise, and at Z, which is nearest to the moon, they will be the highest: but when the waters in the zenith Z are elevated, those in the nadir N are likewise elevated in a similar manner; this is known from experience, for we have high water when the moon is in our nadir, as well as when she is in our zenith; we therefore conclude that, when the moon is in our zenith, our antipodes have high water; the truth of this, as well as every other phenomenon respecting the tides, will be discussed in the following theorems.

THEOREM I.* *The parts of the earth directly under the moon, or where the moon is in the Zenith, as at z* (Plate III. Figure 3.); *and those places which are diametrically opposite to the former, or under the Nadir, as at* N, *will have high water at the same time.*

Because the power of gravity decreases as the square of the distance increases; the waters at A, B, Z, C, D, on the side of the earth next the moon M, will be more attracted by the moon than the central parts O of the earth, and the central parts will be more attracted than the surface N on the opposite side of the earth; therefore the distance between the centre of the earth and the surface of the water, under the zenith and nadir, will be increased. For, let three bodies, Z, O, and N, be equally attracted by M; then it is evident they will all move equally fast towards M, and their mutual distances from each other will continue the same; but if the bodies be unequally attracted by M, that body which is the most attracted will move the fastest, and its distance from the other bodies will be increased. Now, by the law of gravitation, M will attract Z more strongly than it does O, by which the distance between Z and O will be increased. In like manner O being more strongly attracted than N, the distance between O and N will be increased: suppose now a number of bodies, A, B, Z, C, D, F, N, E, placed round O, to be attracted by M, the parts Z and N will have their distances from O increased; while the parts A and D, being nearly at the same distance from M as O is, will not recede from each other, but will rather approach near to O by the oblique attraction of M. Hence if the whole earth were composed of bodies similar to A, B, Z, C, D, F, N, E, and were similarly attracted by M, the section of the earth, formed by a plane passing through the moon and the earth's centre, would be a figure resembling an ellipsis, having its longer axis ZN directed towards the moon; and its shorter axis AD in the horizon. The figure of the earth, therefore, would be an oblong spheroid, having its longer axis directed to the moon; consequently it will be high water in the zenith and nadir at the same time; and as the earth turns round its axis from the moon to the moon again in about 24 hours and 48 minutes, there will be, during that time, two tides of flood and two of ebb.

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* A theorem is a proposition which admits of proof, or demonstration, from definitions clearly understood, and from the known general properties of the subject under consideration.

According to the foregoing explanation of the ebbing and flowing of the sea, every part of the earth is gravitating towards the moon; but as the earth revolves round the sun, every part of it gravitates towards the sun likewise; it may be asked how is this possible at the time of full moon, when the moon is at *m* and the sun at *s*? has the earth a tendency to fall contrary ways at the same time? This is a very natural question; but it must be considered that it is not the centre of the earth that describes the annual orbit round the sun; but the common centre of gravity of the earth and moon together; and that whilst the earth is moving round the sun, it also describes a circle round that centre of gravity, about which it revolves as many times as the moon revolves round the earth in a year.* The earth is therefore constantly falling towards the moon, from a tangent to the circle which it describes round the common centre of gravity of the earth and moon. Let M represent the moon (*Plate* III. *Figure* 4.), TW a part of the moon's orbit, and as the earth is supposed to contain about forty times the quantity of matter which is contained in the moon, the common centre of gravity from the centre of the earth towards the moon will be considerably less than the earth's diameter†, let this common centre of gravity be represented by C. Then whilst the moon goes round her orbit, the centre of the earth describes the circle *d o e* round C, to which circle *o a* is a tangent: therefore when the moon has gone from M to a little past W, the earth has moved from *o* to *e;* and in that time has fallen towards the moon from the tangent at *a* to *e*. This figure is drawn for the new moon, but the earth will tend towards the moon in the same manner during its whole revolution round C.

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* Ferguson's Astronomy, Article 298.

† The common centre of gravity of two bodies is found thus: as the sum of the weights or quantities of matter in the two bodies is to their distance from each other, so is the weight of the lesser body to the distance of the greater from the centre of gravity. Now, if the quantity of matter in the moon be represented by 1, that in the earth by 40, and the distance of the earth from the moon be estimated at 240,000 miles, then 40 + 1

THEOREM II. *Those parts of the earth where the moon appears in the horizon, or* 90 *degrees distant, from the Zenith and Nadir, as at* A *and* D (Plate III. Figure 3.), *will have ebb or low water.*

For as the waters under the zenith and nadir rise at the same time, the waters in their neighbourhood will press towards those places to maintain the equilibrium; and to supply the place of these waters, others will move the same way, and so on to places of 90 degrees distance from the zenith and nadir; consequently at A and D, where the moon appears in the horizon, the waters will have more liberty to descend towards the centre of the earth; and therefore in those places they will be the lowest. Hence it plainly appears, that the ocean, if it covered the whole surface of the earth, would be a spheroid (as was observed in the foregoing theorem), the longer diameter as Z N passing through the place where the moon is vertical, and the shorter diameter as A D passing through the rational horizon of that place. And as the moon apparently[*] shifts her position from

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: 240,000 :: 1 : 5853 miles, the distance of the centre of the earth from the common centre of gravity. Mr. A. Walker, in the 11th lecture of his Familiar Philosophy, ingeniously accounts for its being high water in the zenith and nadir at the same time, in the following manner: — "The parts of the earth that are farthest from the moon, will have a swifter motion round the centre of gravity than the other parts; thus the side *n* will describe the circle *n* V Y, while the side *m* will only describe the small circle *m r s*, round the centre of gravity *c*. Now, as every thing in motion always endeavours to go forward in a straight line, the water at *n* having a tendency to go off in the line *n q*, will in a degree overcome the power of gravity, and swell into a heap or protuberance, as represented in the figure, and occasion a tide opposite to that caused by the attraction of the moon."

[*] The real motion of the moon is from the west towards the east; for if she be seen near any fixed star on any night, she will be seen about 13 degrees to the eastward of that star the next night, and so on. The

east to west in going round the earth every day, the longer diameter of the spheroid following her motion will occasion the two floods and ebbs in about 24 hours and 48 minutes*, the time which any meridian of the earth takes in revolving from the moon to the moon again; or the time elapsed (at a medium) between the passage of the moon over the meridian of any place, and her return to the same meridian.

The meridian altitude of the moon at any place is her greatest height above the horizon at that place; hence the greater the moon's meridian altitude is, the greater the tides will be; for they increase from the horizon D to the point Z under the zenith, and the greater the moon's meridian depression is below the horizon, the greater the tides will be; for they increase from the horizon D towards N, the point below the nadir, and consequently as the tides increase from D to N, the tides in their antipodes will increase from A to Z.

THEOREM III. *The time of high water is not precisely at the time of the moon's coming to the meridian, but about an hour after.*

For the moon acts with some force after she has passed the meridian, and by that means adds to the libratory or waving motion, which the waters had acquired whilst she was on the meridian.

THEOREM IV. *The tides are greater than ordinary twice every month; viz. at the time of new and full moon, and these are called* SPRING-TIDES. (Plate III. Figure 3.)

For at these times the actions of both the sun and moon concur to draw in the same straight line SMZON, and therefore the sea must be more elevated. In conjunction, or at the new moon when the sun is at S and the moon at M, both on the same side of the earth, their joint forces conspire to raise the water in the zenith at Z, and consequently (accord-

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moon goes round her orbit from any fixed star to the same again in 27*d.* 7*h.* 43*m.* 11·5*s.* Hence 27*d.* 7*h.* 43*m.* 11·5*s.* : 360° :: 1*d.* : 13° 10′ 34·68″ the mean motion of the moon in 24 hours.

[*] The mean motion of the moon in 24 hours is 13° 10′ 34·68″ and the mean apparent motion of the sun in the same time is 59′ 8·3″ (*see the note to definition* 61. *page* 13.): the moon's motion is therefore 12° 11′ 26·38″ swifter than the apparent motion of the sun in one day, which, reckoning 4 minutes to a degree, amounts to nearly 48 minutes 46 seconds of time.

ing to Theorem I.) at N the nadir likewise.* When the sun and moon are in opposition, or at the full moon when the sun is at S and the moon at *m*, the earth being between them; while the sun raises the water at Z under the zenith and at N under the nadir, the moon raises the water at N under the nadir and at Z under the zenith.

THEOREM V. *The tides are less than ordinary twice every month; that is, about the time of the first and last quarters of the moon, and these are called* NEAP-TIDES. (Plate III. Figure 3.)

Because in the quadratures, or when the moon is 90 degrees from the sun, the sun acts in the direction S D, and elevates the water at D and A; and the moon acting in the direction M Z or *m* N elevates the water at Z and N; so that the sun raises the water where the moon depresses it, and depresses the water where the moon raises it; consequently the tides are formed only by the difference between the attractive force of the sun and moon.—The waters at Z and N will be more elevated than the waters at D and A, because the moon's attractive force is four* times that of the sun.

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* Mr. Walker says (Lecture 11th), that at new moon, "The sun's influence is added to that of the moon, and the centre of gravity C (*Plate* III. *Figure* 4.) will, therefore, be removed farther from the earth than *m* C, and of course increase the centrifugal tendency of the tide *n*: hence both the attracted and centrifugal tides are spring-tides at that time."——"But spring-tides take place at the full as well as at the change of the moon. Now it has been premised, that if we had no moon, the sun would agitate the ocean in a small degree and make *two* tides every twenty-four hours, though upon a small scale. The moon's centrifugal tide at Z (*Plate* III. *Figure* 3.) being increased by the sun's attraction at S, will make the protuberance a spring-tide; and the *sun's centrifugal tide* at N will be reinforced by the moon's attraction at *m*, and make the protuberance N a spring-tide; so spring-tides take place at the full as well as change of the moon."——Suppose the moon to be taken away (*Plate* III. *Figure* 4.) the common centre of gravity of the earth and the sun would fall entirely within the body of the sun, round which the earth revolves in a year, at the rate of about a degree in a day; hence the parts *n* of the earth farthest from the sun would have a little more tendency to recede from the centre of motion S, than the parts *m* which are the nearest. So that if the sun were on the meridian of any place, it would be high water at that place by the sun's attraction, and it would at the same time be high water at the antipodes of that place by the centrifugal tendency of *n*; consequently, as the earth revolves on its axis from noon to noon in 24 hours, there would be two tides of flood and two of ebb during that time. If the line *m* C be increased when the moon is in conjunction with the sun, so as to cause the point *n* to describe a larger circle than *n* V Y, and also the point *m* to describe a larger circle than *m r s* round the centre of gravity C; when the sun is in opposition to the moon, the line *m* C will be diminished, *n* will therefore describe a smaller circle than *n* V Y, and *m* will describe a smaller circle than *m r s*. Hence it appears that the centrifugal tendency of *n* is greater at the new moon than it is at the full moon, and *m* is likewise more strongly attracted at the same time; the spring-tides at the time of conjunction would therefore be considerably greater than at the time of opposition, were not the moon's centrifugal tide at this time attracted by the sun, and the sun's centrifugal tide added to that caused by the moon's attraction.

THEOREM VI. *The spring-tides do not happen exactly on the day of the change or full moon, nor the neap-tides exactly on the days of the quarters, but a day or two afterwards.*

When the attractions of the sun and moon have conspired together for a considerable time, the motion impressed on the waters will be retained for some time after their attractive forces cease, and consequently the tide will continue to rise. In like manner at the quarters, the tide will be the lowest when the moon's attraction has been lessened by the sun's for several days together. — If the action of the sun and moon were suddenly to cease, the tides would continue their course for some time, as the waves of the sea continue to be agitated after a storm.

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* Sir Isaac Newton, Cor. 3. Prop. XXXVII. Book III., Principia, makes the force of the moon to that of the sun, in raising the waters of the ocean, as 4·4815 to 1 : and in Corol. 1. of the same proposition, he calculates the height of the solar tide to be 2 feet 0¼ inch, the lunar tide 9 feet 1¾ inch, and by their joint attraction 11 feet 2 inches; when the moon is in perigee the joint forces of the sun and moon will raise the tides upwards of 13¼ feet. — Sir Isaac Newton's measures are in French feet in the Principia. I have turned them into English feet.

Mr. Emerson, in his Fluxions, Section III. Prob. 25., calculates the greatest height of the solar tide to be 1·63 feet, the lunar tide 7·28 feet, and by their joint attraction 8·91 feet, making the force of the sun to that of the moon as 1 to 4·4815.

Dr. Horsley, the late bishop of St. Asaph, estimates the force of the moon to that of the sun as 5·0469 to 1. See his edition of the Principia, lib. 3. sect. 3. Prop. XXXVI. and XXXVII.

Mr. Walker, in Lect. 11th of his Familiar Philosophy, states the influence of the sun to be to the influence of the moon to raise the water, as 3 is to 10, and their joint force 13.

THEOREM VII. *When the moon is nearest to the earth, or in Perigee, the tides increase more than in similar circumstances at other times.*

For the power of attraction increases as the square of the distance of the moon from the earth decreases; consequently the moon must attract most when she is nearest to the earth.

THEOREM VIII. *The spring tides are greater a short time before the vernal equinox, and after the autumnal equinox, viz. about the latter end of March and September, than at any other time of the year.* (Plate III. Figure 3.)

Because the sun and moon will then act upon the equator in the direction *a f* B, consequently the spheroidal figure of the tides will then revolve round its longer axis, and describe a greater circle than at any other time of the year; and as this great circle is described in the same time that a less circle is described, the waters will be thrown more forcibly against the shores in the former circumstances than in the latter.

THEOREM IX. *Lakes are not subject to tides; and small inland seas, such as the Mediterranean and Baltic, are little subject to tides. In very high latitudes north or south the tides are also inconsiderable.*

The lakes are so small, that when the moon is vertical she attracts every part of them alike. The Mediterranean and Baltic seas have very small elevations, because the inlets by which they communicate with the ocean are so narrow, that they cannot, in so short a time, receive or discharge enough to raise or lower their surfaces sensibly.*

THEOREM X. *The time and height of the tides may be very different according to the situations of places.*

In some places, the tide-wave, rushing up a narrow channel, is suddenly raised to an extraordinary height. At Annapolis, in the Bay of Fundy, it rises 120 feet. Even at Bristol, the difference of high and low water occasionally amounts to 50 feet.†

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* The rise of water in the Mediterranean is found to be earlier by four hours on the Barbary than on the Spanish side.

† At Dover the tide rises about 25 feet, and at St. Maloes, on the coast

GENERAL OBSERVATIONS.

The new and full moon spring-tides rise to different heights.

The morning tides differ generally in their rise from the evening tides.

In winter the morning tides are highest.

In summer the evening tides are highest.

The tides follow, or flow towards the course of the moon, when they meet with no impediment. Thus the tide on the coast of Norway flows to the south (towards the course of the moon); from the North-cape, in Norway, to the Naze at the entrance of the Scaggerac, or Cattegat Sea, where it meets with the current which sets constantly out of the Baltic Sea, and consequently prevents any tide rising in the Scaggerac. The tide proceeds to the southward, along the east coast of Great Britain, supplying the ports successively with high water, beginning first on the coast of Scotland. Thus it is high water at Tynemouth Bar, at the time of new and full moon, about three hours after the time of high water at Aberdeen; it is high water at Spurn-head about two hours after the time of high water at Tynemouth Bar; in an hour more it runs down the Humber, and makes high water at Kingston-upon-Hull; it is about three hours running from Spurn-head to Yarmouth Road; one hour in running from Yarmouth Road to Yarmouth Pier; two hours and a half running from Yarmouth Road to Harwich; one hour and a half in passing from Harwich to the Nore: from whence it proceeds up the Thames to Gravesend and London.*

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of Normandy, about 50 feet. At the Friendly Islands, near the middle of the Southern Ocean, the difference between high and low water does not exceed two or three feet. The usual rise in the middle of the ocean is rarely above three or four feet. In explanation of these differences, Dr. Traill has justly remarked, that the phenomena of the tides accord well with the theory in the open sea; but in the vicinity of land, amongst numerous islands, or in deep inland basins, their regularity is affected by various causes, — as the occurrence of strong gales in particular directions, the form of points of land, banks, and shoals, and the mechanical influence of narrow channels. It is worthy of remark that, although the times of high and low tide may thus differ at different places, these differences are periodical, and are comprised within extremes which easily admit of calculation.

* The tides of the German Ocean take twelve hours to reach London Bridge: hence when it is high water at the latter place, a new tide is

From the Nore the tide continues to flow southward to the Downs and Goodwin Sands, between the North and South Foreland, in Kent, where it meets the tide which flows out of the English Channel, through the Strait of Dover.

While the tide, or high water, is thus gliding to the southward, along the eastern coast of Great Britain, it also sets to the southward, along the western coasts of Scotland and Ireland; but, on account of the obstructions it meets with from the Western Islands of Scotland, and the narrow passage between the north-east of Ireland and the south-west of Scotland, the tide in the Irish Sea comes round by the south of Ireland, through St. George's Channel, and runs in a north-easterly direction till it meets the tide between Scotland and Ireland, at the north-west part of the Isle of Man. This may be naturally inferred from its being high water at Waterford above three hours before it is high water at Dublin, and it is high water at Dundalk Bay and the Isle of Man nearly at the same time. That the tide continues its course southward may be inferred from its being high water at Ushant, opposite to Brest, in France, about an hour after the time of high water at Cape Clear, on the southern coast of Ireland. Between the Lizard Point, in Cornwall, and the island of Ushant, the tide flows eastward, or east-north-east, up the English Channel, along the coasts of England and France, and so on through the Strait of Dover, till it comes to the Goodwin Sands or Galloper, where it meets the tide on the eastern coast of England, as has been observed before. The meeting of these two tides contributes greatly towards sending a powerful tide up the river Thames to London; and, when the natural course of these two tides has been interrupted by a sudden change of the wind, so as to accelerate the tide which it had before retarded, and to drive back that tide which had before been driven forward by the wind, this cause has been known to produce twice high water in the course of three or four hours.* The above account of the

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commencing in the former. Thus it is high water at the Nore and at London Bridge at the same time, and it is low water between these two places.

* In narrow rivers with wide mouths the tides are frequently very high, and rise suddenly. This is owing to the narrow channel preventing the free entrance of the water: the tide then accumulates and forms a dangerous bank of water. In the Severn the head of the tide is said to reach sometimes ten feet. The rivers of Scotland are subject to these accumulations.

British tides seems to be opposed to the general theory of the motion of the tides, which ought always to follow the moon, and flow from east to west; but to allow the tides their full motion, the ocean in which they are produced ought to extend from east to west at least 90 degrees, or 6255 English miles; because that is the distance between the places where the water is the most raised and depressed by the moon. Hence it appears that it is only in the great oceans that the tide can flow regularly from east to west; and hence we also see why the tides in the Pacific Ocean exceed those in the Atlantic, and why the tides in the torrid zone, between Africa and America, though nearly under the moon, do not rise so high as in the temperate zones northward and southward, where the ocean is considerably wider. The tides in the Atlantic, in the torrid zone, flow from east to west, 'till they are stopped by the continent of America; and the trade winds likewise continue to blow in that direction. When the action of the moon upon the waters has in some degree ceased, the force of the trade winds, in a great measure, prevents their return towards the African shores. The waters thus accumulated* in the Gulf of Mexico return to the Atlantic, between the island of Cuba, the Bahama islands, and East Florida; and, aided by the effect of a high temperature, form that remarkably strong current called the Gulf Stream. This proceeds in a course northwards and eastwards, until it meets the great oceanic current from the northern seas.†

CHAPTER VII.

Of the natural Changes of the Earth. Of Mountains, Volcanoes, and Earthquakes. Of Thermal Springs.

THE highest mountains in the New World are the Andes‡, in South America, which extend nearly 4300 miles in length, from the province of Quito to the strait of Magellan; the highest, called Nevada de Sorata, in Bolivia, or Upper Peru, is said to be 25,250 feet, or nearly five miles above the level of the sea. The next highest of these mountains is Illimani, Peru; the summit of which exceeds 24,200 feet. Chimborazo, which was formerly supposed to be the highest of the Andes, is only 21,420 feet; 5000 of which, from the summit, are always covered with snow. From experiments made with a barometer* on the mountain Cotopaxi, another part of the Andes, it appeared that its

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* To show that an accumulation of water does take place in the Gulf of Mexico, a survey was made across the Isthmus of Darien; when the water on the Atlantic was found to be fourteen feet higher than the water on the Pacific side. Walker's Familiar Philosophy, Lecture XI.

† The Gulf Stream is known to navigators by the waters having a temperature from 6° to 8° higher than those of the open sea. See p. 91.

‡ The *Himmaleh* or *Himalaya* mountains (*the abode of snow*) exceed

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in height the Andes, or any other mountains on the face of the globe. The highest mountain in the world is Dhawalagiri, one of the Himalaya mountains, north of Hindostan: — its most elevated summit is said to be about 28,000 feet. The next highest is Chamalari, which is 27,200 feet above the level of the sea. They are covered with perpetual snow 12,000 feet from the summit. The following is a list of the altitudes of a few of the most elevated mountains in the world: —

	Mountains.	*Situation.*	*Feet.*
1.	Dhawalagiri (*Himalaya*),	N. of Hindostan	28,000
2.	Chamalari (ditto)	ditto	27,200
3.	Hindoo Koosh	ditto	20,000
4.	Nevada de Sorata (*Andes*)	Bolivia, Peru	25,250
5.	Illimani (ditto)	ditto	24,200
6.	Chimborazo (ditto)	ditto	21,420
7.	Cotopaxi (ditto)	Colombia	18,890

IN EUROPE.

	Chains of.	*Loftiest Mountain.*	*Feet.*
1.	Alps	Mont Blanc	15,810
2.	Pyrenees	Pic Nethou	11,168
3.	Carpathian	Lomnitz	8,779
4.	Turkey	Tchar Dagh	10,000
5.	Greece	Guiona	8,239
6.	Apennines	Monte Corvo	9,523
7.	Scandinavian	Snae Halten	8,122
8.	Spain and Portugal	Cerro Mulhaçen, Spain	11,600
9.	France	Pic de Soucy	6,223
10.	Germany	Riesen Gebirge	5,000
11.	Scotland	Ben Nevis	4,368
12.	England and Wales	Snowdon	3,571
13.	Ireland	Carn Tual	3,410

* The quicksilver in a barometer falls about 1-tenth of an inch for every 32 yards of height; so that if the quicksilver descend 3-tenths of an inch, in ascending a hill, the perpendicular height of that hill will be 96 yards. This method is liable to error See the Causes which affect the Accuracy of Barometrical Experiments, in the Edinburgh Philosophical Transactions, by Mr. Playfair; also in Keith's Trigonometry, fourth edition, p. 97.

summit is elevated 6252 yards, or upwards of 3½ miles. The Peak of Teneriffe, in the island of that name, is 12,182 feet, or upwards of two miles high. Mont Blanc, the highest mountain in Europe, is 15,810 feet above the level of the sea. These irregularities, although very considerable with respect to us, are nothing when compared with the magnitude of the globe. Thus, if an inch were divided into one hundred and eleven parts, the elevation of Chimborazo, on a globe of eighteen inches in diameter, would be represented by *one*[*] of these parts.

Hence the earth, which appears to be crossed by the enormous height of mountains, and cut by the valleys and the great depth of the sea, is nevertheless, with respect to its magnitude, only very slightly furrowed with irregularities, so trifling indeed as to cause no difference in its figure.

The more remarkable changes which the surface of the earth has undergone may be reduced to two general causes, floods and earthquakes.

FLOODS. The real or fabulous deluges mentioned by the ancients may be reduced to six or seven, and though some authors have endeavoured to represent them all as imperfect traditions of the universal deluge recorded in the sacred writings, the Abbé Mann[†], from whom the following observations are extracted, does not doubt but that they refer to various real and distinct events of the kind.[‡]

1. The submersion of the *Atlantis* of Plato probably was the real subsidence of a great island stretching from the Canaries to the Azores, of which those groups of small islands are the relics.

2. The deluge in the time of Cadmus and Dardanus, placed by the best chronologists in the year before Christ 1477, is said by Diodorus Siculus to have inundated Samothrace, and the Asiatic shores of the Euxine Sea.

3. The deluge of Deucalion, which the Arundelian marbles[§], or the Parian chronicles, fix at 1529 years before Christ, overwhelmed Thessaly.

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[*] For a view of the comparative elevation of these mountains see Plate VIII.

[†] Vide Nouveaux Mémoires de l'Académie Impériale et Royale de Sciences et des Belles Lettres, de Brussels, tome premier, 1788.

[‡] M. Biot has discovered, in the annals of the *Chinese*, historic evidences of two great deluges, the most recent of which they place as far back as the 23d century before our era.

[§] Ancient stones, whereon is inscribed a chronicle of the city of Athens, engraven in capital letters, in the island of Paros, one of the Cyclades, 264 years before Christ. They take their name from Thomas, Earl of Arundel, who procured them from the East. They were presented to the University of Oxford in the year 1667, by the Hon. Henry Howard, afterwards Duke of Norfolk, grandson to the first collector of them.

4. The deluge of Ogyges, placed by Acusilaus in the year answe to 1796 before Christ, laid waste Attica and Bœotia. With the poe and fabulous accounts of Deucalion's flood are mingled several circ stances of the universal deluge; but the best writers attest the loc and distinctness, both of the flood of Deucalion and Ogyges.

5. Diodorus Siculus, after Manetho, mentions a flood which i dated all Egypt in the reign of Osiris; but, in the relations of event, are several circumstances resembling the history of Noah's floo

6. The account given by Berosus the Chaldean of an universal de in the reign of Xisuthrus evidently relates to the same event as the f of Noah.

7. The Persian Guebres, the Brahmins, Chinese, and Americ have also their traditions of an universal deluge. The account of deluge in the Koran has this remarkable circumstance, that the w which covered the earth are represented as proceeding from the bo over of the caldron [*], or oven, *Tannour*, within the bowels of the ea and that, when the waters subsided, they were swallowed up agai the earth.

The abbé next gives a summary of the Scripture account of N flood, and points out very clearly that part of the waters came from atmosphere, and part from under ground agreeably to the 11th vers the 7th chapter of Genesis.

Earthquakes are another great cause of the changes made in earth. From history we have numerous instances of the dreadful ef of these terrible phenomena. Pliny has not only recorded several traordinary phenomena which happened in his own time, but has like borrowed many others from the writings of more ancient nations.

1. A city of the Lacedemonians was destroyed by an earthquake, its ruins wholly buried by the mountain Taygetus falling down them.[†]

2. In the books of the Tuscan learning, an earthquake is recor which happened within the territory of Modena, when L. Martius S. Julius were consuls, which repeatedly dashed two hills against other; with this conflict all the villages and many cattle were destro

3. The greatest earthquake mentioned in history was that w happened during the reign of Tiberius Cæsar, when twelve cities of were laid level in one night.[‡]

4. The eruption of Vesuvius, in the year 79[§], overwhelmed the famous cities of Herculaneum[‖] and Pompeii, by a shower of st

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[*] This circumstance is mentioned here, because it agrees with Whitehurst's Theory of the Earth; he supposes the flood was occasi by the expansive force of fire generated at the centre of the earth.

[†] Pliny's Natural History, chap. 79.

[‡] Pliny, chap. 84.

[§] Pliny lost his life by this eruption. He was suffocated in co quence of his having approached too near to the mountain.

[‖] This city was discovered in the year 1736, eighty feet below surface of the earth; and many of the streets of Pompeii have since discovered.

cinders, ashes, and fine volcanic sand. The buildings of Pompeii were totally covered by them to the depth of many feet. Herculaneum is situated about four miles from the crater, and Pompeii about six.

By the violence of this eruption, ashes were carried over the Mediterranean Sea into Africa, Egypt, and Syria: and at Rome they darkened the air on a sudden, so as to hide the face of the sun.*

5. In the year 1533, large pieces of rock were thrown to the distance of fifteen miles, by the volcano Cotopaxi in Peru.†

6. On the 29th of September, 1535, previous to an eruption near Pouzzuoli, which formed a new mountain of three miles in circumference, and upwards of 1200 feet perpendicular height, the earth frequently shook, and the plain lying between the lake Averno, mount Barbaro, and the sea was raised a little; at the same time the sea, which was near the plain, retired two hundred paces from the shore.‡

7. In the year 1538, a subterranean fire burst open the earth near Pouzzuoli, and threw such a vast quantity of ashes and pumice stones, mixed with water, as covered the whole country, and thus formed a new mountain, not less than three miles in circumference, and near a quarter of a mile perpendicular height. Some of the ashes of this volcano reached the vale of Diana, and some parts of Calabria, which are more than one hundred and fifty miles from Pouzzuoli.§

8. In the year 1538, the famous town called St. Euphemia, in Calabria Ulterior, situated at the side of the bay under the jurisdiction of the knights of Malta, was totally swallowed up with all its inhabitants, and nothing appeared but a fetid lake in the place of it.||

9. A mountain in Java, not far from the town of Panacura, in the year 1586, was completely levelled by a violent eruption, whereby ten thousand people perished in the underland fields.¶

10. In the year 1600, an earthquake happened at Arquepa, in Peru; accompanied with an irruption of sand and ashes, which continued during the space of twenty days, from a volcano breaking forth; the ashes falling in many places above a yard thick, and in some places more than two, and where least, above a quarter of a yard deep, which buried the corn grounds of maize and wheat. The boughs of trees were broken, and the cattle died for want of pasture; for the sand and ashes thus erupted covered the fields ninety miles one way, and one hundred and twenty another way. During the eruption, thunder and lightning were heard and seen ninety miles round Arquepa, and it was so dark whilst the showers of ashes and sand lasted, that the inhabitants were obliged to burn candles at mid-day.**

11. On the 16th of June, 1628, there was so terrible an earthquake in the island of St. Michael, one of the Azores, that the sea near it opened, and in one place where it was one hundred and sixty fathoms

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* Burnet's Sacred History, vol. ii. p. 85.

† Ulloa's Voyage to Peru, vol. i. p. 324.

‡ Sir William Hamilton's Observations on Vesuvius.

§ Ibid. p. 128.

|| Dr. Hooke's Post. p. 306.

¶ Varenius's Geography, vol. i. p. 150.

** Dr. Hooke's Post p. 304.

deep, threw up an island; which in fifteen days was three leagues long, a league and a half broad, and 360 feet above the water.*

12. In the year 1631 vast quantities of boiling water flowed from the crater of Vesuvius previous to an irruption of fire; the violence of the flood swept away several towns and villages, and some thousands of inhabitants.†

13. In the year 1632, rocks were thrown to the distance of three miles from Vesuvius. ‡

14. In the year 1646, many of those vast mountains the Andes § were quite swallowed up and lost. ‖

15. In the year 1692, a great part of Port Royal in Jamaica was sunk by an earthquake, and remains covered with water several fathoms deep; some mountains along the rivers were joined together, and a plantation was removed half a mile from the place where it formerly stood.¶

16. On the 11th of January, 1693, a great earthquake happened in Sicily, and chiefly about Catania; the violent shaking of the earth threatened the whole island with entire desolation. The earth opened in several places in very long clefts, some three or four inches broad, others like great gulfs. Not less than 59,969 persons were destroyed by the falling of houses in different parts of Sicily.**

17. In the year 1699, seven hills were sunk by an earthquake in the island of Java, near the head of the great Batavian river, and nine more were also sunk near the Tangarang river. Between the Batavian and Tangarang rivers, the land was rent and divided asunder, with great clefts more than a foot wide.††

18. On the 20th of November, 1720, a subterraneous fire burst out of the sea near Tercera, one of the Azores, which threw up such a vast quantity of stones, &c. in the space of thirty days, as formed an island about two leagues in diameter and nearly circular. Prodigious quantities of pumice-stone, and dead fish, were found floating on the sea for many leagues round the island. ‡‡

19. In the year 1746, Callao, a considerable garrison town and seaport in Peru, containing 5000 inhabitants, was violently shaken by an earthquake on the 28th of October; and the people had no sooner begun to recover from the terror occasioned by the dreadful convulsion, than the sea rolled in upon them in mountainous waves, and destroyed the whole town. The elevation of this extraordinary tide was such as conveyed ships of burden over the garrison walls, the towers, and the town.

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* Sir W. Hamilton's Observations on Vesuvius and Etna, p. 159.

† Ibid.

‡ Baddam's Abridg. Phil. Trans. vol. ii. p. 417.

§ M. Condamine represents these mountains and the Apennines as chains of volcanoes. See his Tour through Italy, 1755.

‖ Dr. Hooke's Post. p. 306.

¶ Lowthorp's Abridg. Phil. Trans. vol. ii. p. 417.

** Ibid. vol. ii. pp. 408, 409.

†† Ibid. vol. ii. p. 419.

‡‡ Eames's Abridg. Phil. Trans. vol. vi. part ii. page 203.

The town was rased to the ground, and so completely covered with gravel, &c. that not a vestige of it remained.*

20. The facts connected with the great earthquake of Lisbon, whicl curred on the 1st of November, 1755, were accurately observed, an following account of this terrific convulsion of nature is given by fessor Johnston. "Suddenly a sound like subterranean thunder heard; this was immediately succeeded by a violent shock, which molished the greater part of the city, and in the course of *six mi* 60,000 persons perished. The movement of the earthquake was dulatory, and it was calculated that it travelled at the rate of tw miles a minute. A space more than four times the extent of Europ nearly one-twelfth of the superficial area of the globe, was shake this earthquake, which had for the axis of its shock, a line exten from Mogadore on the coast of Morocco, along the west coast of Port to Cork in the south of Ireland. From Lisbon, the central point line of devastation extended northwards to Oporto, and southw to Ayamonte, where the Guadiana falls into the Bay of Cadiz. W this entire space, the sea, fearfully agitated by the concussion of its caused the greatest destruction. At Cadiz a wave sixty feet high r over the land; and at Lisbon the sea rose fifty feet above its usual l At Kinsale in Ireland, the sea rolled into the harbour, and overfl the market-place; and at Funchal in Madeira, it rose to fifteen above the highest water-mark. The space within which this earthq was observed on land extended in an elliptical form from the isla Madeira to Abo in Finland; and from Scotland to Sardinia. In land, the water in Loch Lomond, Loch Katrine, Loch Long, and Ness, was observed to rise and fall repeatedly, to an extent of t three feet; and this movement of the surface of the water was espe observable in the lakes of Germany, Switzerland, and France, as w in those of Scandinavia. The agitation of the waves of the sea exte even to the West Indies, where the islands of Antigua, Barbadoes, daloupe and Martinique were overflowed; and a ship forty leagu the west of St. Vincent suffered a violent shock. At the same tim unusual movement was observed on the surface of the Lake Onta North America.† The concussion assumed the form of an ellip

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* In 1842 Hayti (St. Domingo) was visited by an earthquake destroyed ten thousand of its inhabitants.

† The earthquake which desolated Calabria in the year 1783 was to 100,000 persons. The shocks began on the 5th February, and tinued at intervals, with different degrees of violence, for more than months, and were felt over an area of 500 miles. It destroyed towns and villages occupying a circuit of nearly 50 miles in dian lying between 38 and 39 degrees of latitude, and extending almost the western to the eastern coast of the southernmost part of Italy, b doing considerable damage to places more remote from its origin, wh supposed to have been either immediately under the town of Oppi under some part of the sea between the west of Italy and the vo island of Stromboli. Both this island and Mount Etna exhibite pearances of eruption during the continuance of this scene of ext

which the longest diameter characterised by the destruction which was produced in its course, extended over three hundred miles. The space over which the shock was perceptibly felt extended to 2700 miles, and the area of vibration, or the greatest extent over which water was observed to oscillate at the surface, extended to about 4000 miles!"

21. The greatest eruption of Vesuvius happened in July, 1794*, being

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devastation, previous to which neither of them had smoked so much as usual.

* Several eruptions of Mount Vesuvius have occurred during the present century, some of the principal effects of which have been to produce considerable changes in and about the crater. In an eruption which commenced on the 22d and terminated on the 26th of December, 1817, two or three small conical hillocks, the one of which stood near the eastern edge, and the other upon the western ridge, of the crater, were entirely swallowed up, and the recent lava disposed itself in the manner of a wall, fortifying, as it were, the ancient crater upon the eastern and western sides; convex and very irregular upon the north and south. Of this wall, the whole of which was extremely hot, and apparently incandescent in the interior, some parts were quite even and regular. Upon the south, a very gently inclined plane was produced, covered with fine sand; the former edge of the crater about this part having been entirely destroyed. By the eruption of 1822 very great changes were again effected in the crater of this mountain, which for a century past had been gradually filling up by lava boiling up from beneath, as well as by scoriæ falling from the explosions of smaller mouths, which were formed at intervals on its base and sides, thus giving it something of the appearance of an enclosed rocky plain, covered with blocks of lava and cinders, and traversed by numerous fissures, from which clouds of vapour were continually rising. By the violent explosions which took place during this eruption, which began in October, and lasted upwards of twenty days, the whole of this accumulated mass was entirely broken up and thrown out, leaving an immense chasm of an irregular shape, somewhat elliptical, about three miles in circumference. Eruptions occurred in the years 1822, 1828, 1831, and 1832. [A short time after the great eruption of 1828 (in March, 1829), the writer ascended Vesuvius, while it was still in action, care being taken to make the ascent on the windward side. The crater then had a circumference of about two miles, and it was 700 feet in depth, the sides being in some places almost perpendicular. The edge of the crater was in some parts a sharp inaccessible ridge; in other places it had a sloping breadth of from five to fifteen feet. The bottom consisted of hard and firm lava, still retaining so much heat as to burn the snoes. It was traversed at intervals by long cracks or fissures, some of them three feet wide, and through these a bed of red hot lava might be seen rolling in a molten state, at no great depth below. In the centre of the area was a small cone, out of which large masses of lava were ejected at intervals. These were thrown upwards in sheets with considerable velocity, rising to the height of from 700 to 1000 feet, assuming the form of black flaky masses, in the midst

the most violent and destructive of any mentioned in history, except those in 79 and 1631. The lava covered and totally destroyed 5000 acres of rich vineyards and cultivated lands; and overwhelmed the town of Torre del Greco: the inhabitants, amounting to 18,000, fortunately escaped; and the town is now rebuilt on the lava that covers their former habitations. [The lava retained its plastic condition while flowing through the town. It filled the houses, and poured out of the upper windows. The current in passing down the sides of the mountain caused the destruction of a forest, the trees being burnt wherever they were exposed to air, but the trunks remained in the midst of the lava as masses of charcoal. The current which destroyed Torre del Greco had a length of 23,000 feet; and, according to the calculation of the Neapolitan academicians, it contained 46,098,766 cubic feet of solid lava.

In traversing the houses the molten lava converted the whole of the glass utensils into what is called Reaumur's porcelain, a substance resembling stone ware. All domestic utensils of brass underwent a remarkable change, being fused and decomposed; the copper being converted to sulphuret and blue carbonate, and the zinc to sulphate. Several brass candlesticks thus changed are shown to visitors at the museum of Portici. The danger had been for some time impending: the current slowly descended upon the town, spreading in its descent, and no human

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of the white smoke: when they fell on the lava below, they splashed like pasty substances, and were evidently red hot within. An eruption of this kind took place at intervals of two or three minutes, and it was preceded by a deep rumbling sound in the earth, and a trembling of the whole mountain, so that the landscape of the country beneath appeared to be in a kind of vibratory motion. Some portions of the lava, weighing probably twenty and thirty pounds, traversed the air with such velocity that they appeared more like dust or feathers impelled by some extraordinary force, than heavy masses of stony matter. The inner walls of the crater, for many thousand square yards, were covered with layers of sal ammoniac, sulphur, sulphates, and sulphurets, presenting the appearance of variegated zones of a white, yellow, blue, and green colour. A change of wind would have rendered the position of a spectator dangerous, as the gases evolved from the crater were of a most poisonous kind. The writer recognised among them the sulphurous acid, muriatic acid, and sulphuretted hydrogen gases. In descending the mountain, a large mass of lava was pointed out by the guide as having been ejected in 1822: it measured 36 feet in circumference.] On the morning of January 1st, 1839, Vesuvius again burst forth with an explosion like the report of a cannon, and a dense cloud of smoke and ashes soon covered Naples. On the evening of the 2d, the mountain emitted flames, and the lava flowed down between Portici and Torre del Greco, committing great ravages. [There are about sixty eruptions of Etna on record, and many more of Vesuvius. Vesuvius was not known as a volcano until the reign of Titus; although the buildings of Pompeii were constructed of lava, and the streets were paved with it! Stromboli is always in action, and has been so since 300 B. C.]

power could avert the catastrophe. The flow of lava was only stopped by reaching the sea.

The hermit's house, which is built upon a peak in a valley, at the elevation of 2000 feet, was completely surrounded by the melted lava, the current being split by the promontory, and passing on each side so as to completely enclose it. The lava soon cooled on the outside, but it retained its heat for a considerable period within. The writer saw from the summit of Vesuvius in 1829 the remains of this great current of lava, which led to such destruction. It was spread in a vast sheet down the side of the mountain. The rough projecting masses gave it the appearance of a black sea, the waves of which had become suddenly petrified.]

22. VOLCANOES. Volcanoes are spread over the whole of the earth. They appear to be fiery vents in the superficial crust, through which vast masses of igneous rocks are raised from the interior and poured out upon the surface of the globe. At the present time it is calculated that there are 270 volcanoes in a state of activity, of which no less than 190 are on the islands or around the shores of the Pacific Ocean. They rise up through the sea as well as on land, although in general they are either insular or littoral,—in the midst of eternal ice, as Mount Erebus, in latitude 75° South, which is 12,400 feet in elevation*, or under the equator, as Cotopaxi, which reaches nearly 19,000 feet above the sea-level.† From the similarity of the phenomena which accompany their eruptions, and the nature of the substances ejected, it is evident that they must proceed from one common source; and there is every reason to believe that they have some general connection below the superficial crust of the globe. They appear to demonstrate the existence within the interior, of a full red heat, extending from the equator to the poles.

23. CAUSES OF VOLCANIC ERUPTIONS. Various hypotheses have been brought forward to account for the phenomena of volcanic eruptions. That these fiery mountains have been in action since the first creation of the earth is undoubted, as extinct volcanoes are found scattered largely over its surface. The most probable opinion is that the phenomena are

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* This volcano, which is covered from its base to its summit with perpetual snow, was discovered by Sir James Ross in 1841. On the 28th January, it was observed to project a column of smoke and ashes to the height of 2000 feet. The column had a diameter of between two and three hundred feet!

† No volcanoes are known to exist in Africa.

due to the heat which is supposed to exist within the interior of the globe; and that at a certain depth below the surface, the earthy and metallic constituents are constantly in a molten state. In all eruptions there is a most abundant extrication of gaseous matter, consisting of aqueous vapour, muriatic acid, and other gases: when these can find no vent through the cracks or the fissures by which volcanoes communicate with the subjacent strata, they accumulate until their elastic force is sufficient to overcome the resistance; and they then either burst through the crater, carrying before them masses of rock and melted lava, or through the side of the mountain, destroying the old, and forming a new crater. The aperture of exit is always formed where there is the least resistance. The force with which large stones are ejected cannot be compared with any of the forces with which we are acquainted. Some masses of large size, observed by Sir William Hamilton, were carried upwards of 2000 feet into the air during an eruption of Vesuvius.* Independently of these stones, the red heat of which is plainly perceptible in the darkness of night, a fine ash or dust (*lapilli*) is carried up to a great elevation in the midst of the aqueous vapour, and is then drifted to considerable distances by means of the upper current of air into which it passes. In this way the whole kingdom of Naples has been more or less covered by the dust of Vesuvius. In the eruption of Hecla, 21st September, 1845, the fall of ashes extended to the Orkney Islands, a distance of nearly seven hundred miles.

The lava when examined consists of compounds of potassium, sodium, iron, titanium and aluminum: and on this fact the chemical theory of volcanic action has been based. Most active volcanoes are situated on islands, or on continents in the vicinity of the sea. The late Sir H. Davy advocated the opinion that some miles below the earth's surface, the strata were composed of the alkaligenous metals in a pure state,—that cracks or fissures formed in the earth allowed vast quantities of water to have access to them; and thence arose an intense heat, adequate to produce fusion, and an abundant evolution of gas and vapour, which, when it had acquired sufficient force, rent asunder the crater or sides of the volcano. In reference to this theory, Mr. Phillips very properly asks, what opens the fissures and gives passage to the water at the base of volcanic mountains? To this might be added another question, which appears strongly adverse to this chemical hypothesis, namely, How is it that these highly elastic products do not escape through the fissures which allow the water to reach the metals, instead of lifting almost from its base an enormous mountain? Some of the volcanoes of the Andes are one hundred and thirty, and one hundred and fifty miles from the borders of the Pacific; and in Central Asia the volcanoes of Thiouchan, or the Celestial Mountains, are 1500 miles from the nearest sea: hence it would be necessary to assume the existence of cracks or fissures of enormous extent, in order to render the hypothesis tenable! It is, however, palpably insufficient. Whatever force causes the supposed crack or fissure, would suffice to account for the phenomena of volcanoes. The most probable theory is, that their action is due to the interior heat of the earth, occasionally leading to the evolution of a large quantity of gaseous matter from unknown sources. When this cannot find a ready escape through the fiery vent, an eruption occurs, the molten mass of the interior being poured out.

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* The height is estimated by the time which the stones occupy in falling. It is a most extraordinary spectacle to witness, on a dark night, the projection from the crater of these red-hot masses of lava. In 1829 they were plainly visible to the writer at a distance of four miles in the midst of a cloud of lurid smoke which surrounded the crater.

The vesicular character of lava shows that the gaseous matter is diffused, probably by reason of the great pressure, throughout the whole of the stony mass. In lava deposited in hollows, where it cannot flow, the cells are more or less spherical. In the lava which has flowed in a current down the side of the mountain, the cells are always drawn into an elliptical form.*

24. CAUSES OF EARTHQUAKES. Accompanying every vol-

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* It is worthy of remark, that before an eruption of Vesuvius takes place, many of the wells in the country round, become dry, and are filled with carbonic acid. This and other fatal gases are also poured out on the sides of the mountain, and lead to the destruction of many wild animals.

The celebrated poison valley of Java is an extinct volcanic crater, filled to a certain level with carbonic acid. Those persons who visited it, as well as all animals that attempted to cross it, were destroyed; not by canic eruption, especially if it take place on a great scale, there is a perceptible trembling of the earth: on the summit of the volcano it is felt as a vibratory motion. This undoubtedly depends upon the effort made by the gases and vapours to escape from the obstruction offered by the molten substances by which the vent of the volcano is blocked up: for the rumbling noise and motion cease immediately after the ejection, and there is an interval of quiet, until they have again collected in sufficient force to remove the lava.

Earthquakes probably depend on the same causes as volcanic eruptions, *i. e.* the effect of the interior heat of the globe acting by gaseous matter upon the strata, which forms the superficial crust. This leads to the sudden rending of the strata beneath, preceded by a rumbling noise, and violent explosions: and the shock then subsides. In some cases the force is sufficiently strong, and sufficiently violent, to form large fissures in the earth, as in the Lisbon earthquake of 1755. By careful observations made in South America, Mr. Darwin ascertained that the subterranean force was relieved by an earthquake, precisely in the same manner as by a volcanic eruption. Although earthquakes are common in volcanic countries, still they occur in regions far removed from volcanoes; and although they may depend on the same general cause, they appear to have no necessary connection with them. Earthquakes have been perceived in Great Britain, and other parts of Europe, and there has

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the fabulous poison tree, but by the invisible carbonic acid, into which they were obliged to plunge.

The principal active volcanoes of Europe are —

Names.	*Height.*	*Date of last Eruption.*
Etna	10874 feet	1832.
Vesuvius	3948 —	1846.
Stromboli	2957 —	Constant.
Hecla	5110 —	1845.
Teneriffe		
Pico de Teyde	12182 —	
Pico di Chaborra	9886 —	1798.

The loftiest active volcano on the globe is Gualatieri, in the Andes. Its peak reaches the height of 22,000 feet above the sea-level: next to this comes Antisana, about 19,000 feet. The loftiest extinct volcano (Mount Ararat) in the old world reaches 17,200 feet; while the loftiest active volcano is Kluitchewskaja, in central Asia, the peak of which reaches the elevation of 15,600 feet.

been no accordance between their occurrence and the recorded eruptions of the nearest volcanoes.

The influence of an earthquake may be perceived over a large portion of the earth's surface, and the deeper the subterranean force, the greater the extent over which the undulatory motion is likely to be felt.* No country can therefore be considered exempt from them. Many slight shocks have been perceived of late years at Comrie in Perthshire †; and some have also been felt on the southern coast of England, but their occurrence in the British isles, must be considered as an exceedingly rare event. Earthquakes are felt in the open ocean, as well as on land: and the feeling experienced by those on board of a vessel, is, as if the ship had grated with its keel upon a sunken rock. An English vessel, sailing from Liverpool to Bombay, experienced a shock of this kind, on February 9th, 1835, (north latitude 0°.57, and west longitude 23°.19,) in the middle of the Atlantic Ocean, between the coast of Africa and South America. It seemed as if the keel passed over a coral reef, but, on sounding, no bottom was found at a depth of 120 fathoms!

THERMAL SPRINGS.—This name is applied to springs, the waters of which rise spontaneously, and have a high temperature; they may be regarded as natural *Artesian wells*. Like volcanoes, thermal springs serve to indicate the existence of a high temperature within the interior of the earth. Some of these springs have a temperature approaching the boiling heat of water, but they vary for the most part from 60° to 180°. The hottest spring in Great Britain is that of Bath, 117°; in Ireland, that of Mallow, 72°. Sometimes it happens that cold springs are close to them; but then they undoubtedly proceed from very different depths. These singular anomalies are found in the Feejee Islands in the Pacific, and also at Baden Baden. In Great Britain, hot springs are observed to issue through points of displacement in the strata; and Professor Forbes remarked that the numerous hot springs of the Pyrenees, generally proceeded from the junction of stratified with unstratified rocks. In short, these springs are found to appear in those localities, where there exist natural cracks or fissures in the strata.

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* The great earthquake of Guadaloupe, in 1842, was felt over a space of from sixty to seventy miles in breadth, and three thousand miles in length. The effects of the Lisbon earthquake in 1755 were perceived over a still larger area. The most destructive earthquakes are generally those in which the shock is but momentary. During the great earthquake of Caraccas, by which 10,000 lives were sacrificed, and a flourishing province reduced to ruins, three terrific shocks, each of which lasted from three to four seconds, followed each other within the space of *fifty seconds*: and the great earthquake of Lisbon lasted only about *six minutes!*

† The shock, or succession, generally takes a rectilinear course. A white basin, half filled with treacle, serves to indicate the direction, by the alteration of the level of the liquid during the upheaving. This was employed at Comrie, and found to indicate a direction of the shock from north-east to south-west. The nearest active volcano to Scotland is Hecla. The hill of Arthur's seat, the rocks of Stirling and Dumbarton, with the well marked basaltic columns of the isle of Staffa, clearly point to the ancient operation of volcanoes in that country.

It is not so easy to say by what force these thermal waters are brought to the surface of the earth. The theory of hydrostatic equilibrium will hardly explain the phenomenon; for in some instances, the springs appear to issue far above the level of any source of water which, by its percolation through the earth, would suffice to account for their uninterrupted flow through the long course of ages. The temperature of the Leuker Spring in the Canton of the Valais in Switzerland, is 144°; and it issues from the earth at an elevation of 5000 feet above the level of the sea. This is near the region of eternal snow, and the writer is not aware that there is any source of water above the level of this spring, adequate to its supply on the hydrostatic hypothesis.

The water of these thermal springs does not differ in any remarkable degree from that of other springs. According to Humboldt, the hottest are the purest — the waters contain less saline matter — but in general they are strongly impregnated with gases, apparently condensed under great pressure. Although they issue from depths to which man has never been able to penetrate, they contain the same saline constituents as the cold mineral waters. Some are sulphureous, others chalybeate — the nature of their constituents depending on the chemical composition of the strata through which they rise. The probability is, that the water is nothing more than rain water which has percolated to a great depth, and has thereby acquired a high temperature from contact with the lower strata.

It is a striking fact, and one indicating their close connection with the internal heat of the globe, that these springs are liable to be affected by volcanic eruptions and earthquakes over large tracts of the earth. Those situated near volcanoes either cease flowing or undergo some change of temperature at the time of an eruption. Professor Phillips mentions that in 1755, during the occurrence of the great Lisbon earthquake, the temperature of the thermal spring, called the Source de la Reine, at Bagneres de Luchon in the Pyrenees, was raised 75°. The temperature of this spring is now 152°. This fact appears to furnish a remarkable proof of a subterranean connection existing under the whole peninsula of Spain, from the Pyrenees to the Atlantic, a distance of 600 miles. But, according to Neumann, the influence of this earthquake on thermal springs was perceived at a still greater distance; for while it continued, the Sprudel Spring at Carlsbad, in Bohemia, ceased to flow. The influence was here extended over a distance of 1400 miles!

Thermal springs are found in all parts of the world — in Greenland, Iceland, and in the equatorial regions — in the midst of continents, and in the scattered islands of the Pacific Ocean. The hottest, which either reach the boiling point of water, or have a temperature very near it, are in South America and New Zealand. The hottest springs are not necessarily in the immediate vicinity of volcanoes. Thus Humboldt observes, that the Trincheras and Comangillas springs, in South America, issue from granite, and have a temperature varying from 194° to 207°; while those around the volcanoes of the Andes, vary in temperature from 97° to 131°. One remarkable fact must be here noticed: Humboldt observed in 1800, that the Trincheras Spring had a temperature of 194°. Boussingault examined the same spring in 1823, and found it to have a temperature of 207°: it had thus risen 13° in 23 years. There is a thermal spring in Greenland, that of Ournartok, which has a temperature of 104°; and the intermitting Geyser Springs of Iceland, from which the water is thrown to the height of 100 feet, have the temperature of boiling water (212°.)

The quantity of water which issues from thermal springs is very constant throughout the year. This fact, together with their high temperature, shows that their heat must be entirely independent of atmospheric and solar influence. They may be regarded, indeed, as natural thermometers on a large scale, serving to indicate the heat of the interior of the globe from the equator to the poles. Some of them have been flowing uninterruptedly for upwards of a thousand years; and, so far as we can judge from historical records, without undergoing any marked change of temperature. They were described as hot springs, and used as hot baths by the Romans 1700 years ago. As an illustration, may be mentioned, Nero's Baths, on the coast near Naples: — the water has a temperature of 121°. According to Humboldt, some are now flowing in Greece, which are mentioned by Herodotus and Strabo, and which were used for baths by the Greeks before the time of the Mithridatic war.

The continued flow of these thermal springs, in countries where there are extinct volcanoes, appears to indicate that the effects of subterranean heat are merely suspended; and that the extinct may at any time become suddenly converted into an active volcano. Thus, in the province of Auvergne in Central France, there are several hot springs, one of which has a temperature as high as 176°: others, such as those of Mont d'Or and Vichy, a temperature of about 113°. The view of this district, from the summit of the Puy de Dome, includes no less than 180 volcanic craters; and there is no certain record of any eruption in this region, within the historical period.* These volcanoes, which have covered a large portion of Central France with lava and ashes, must have been extinct for many centuries. They are, indeed, now what Vesuvius was in the seventieth year of the Christian era, immediately prior to the eruption which destroyed Herculaneum and Pompeii. We are in the habit of speaking of them as extinct, but the uninterrupted flow of the thermal springs around them, appears to indicate that the great cause of their former activity is only latent.

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* This mountain derives its name from its being of a bell-shape. Like all volcanoes, active or extinct, it has a conical form: the summit is 3565 feet above the level of the sea. It was in the ascent of this mountain, in 1648, that Pascal first ascertained the pressure of the atmosphere. The barometer stood 3·5 inches higher at the base than at the summit. The ascent amply repays the traveller.

CHAPTER VIII.

Of the Atmosphere, Winds, and Hurricanes.

THE earth is surrounded by a thin fluid mass of matter, a mixture of gases, called the atmosphere*: this matter gravitates towards the earth, revolves with it in its diurnal motion, and goes round the sun with it every year. Were it not for the atmosphere, we should receive and lose the light of the sun suddenly. The phenomena of twilight are therefore due to the refraction of light by this aerial medium, and we thereby enjoy the sun's light for some time before he rises and after he has set; for, on the 21st of June at London, the APPARENT day is 9 min. 16 sec. longer than the astronomical day. This invisible fluid extends to an unknown height; but if, as astronomers generally estimate, the sun begins to enlighten the atmosphere in the morning when he comes within eighteen degrees of the horizon of any place, and ceases to enlighten it when he is again depressed more than 18 degrees below the horizon in the evening, the height of the atmosphere may be calculated to be from 45 to 50 miles.†

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* From *ατμος, vapour; sφαιρα, globus*: the sphere of vapours, because it receives into it all the vapours which rise from the earth.

† Let A*r*B (*Plate* III. *Fig.* 5.) represent the horizon of an observer at A; S*r* a ray of light falling upon the atmosphere at *r*, and making an angle S*r*B of 18 degrees with the horizon (the sun being supposed to have that depression) the angle S*r*A will then be 162 degrees. From the centre O of the earth, draw O*r*, and it will be perpendicular to the reflecting particles at *r*; and by the principles of optics, it will likewise bisect the angle S*r*A. In the right-angled triangle OA*r*, the angle O*r*A = 81°, AO = 3982 miles, the radius of the earth. Hence, by trigonometry,

Sine of O*r*A, 81°	9·9946199
Is to AO, 3982	3·6011013
As radius, sine of 90°	10·0000000
Is to O*r* 4031·76	3·6054814

Now, if from O*r* = 4031·6, there be taken OV = OA = 3982, the remainder V*r* = 49·6 miles is the height of the atmosphere.

The effect of the refraction of light by the atmosphere is also seen in Plate I. fig. 3. At a height of 45 miles, the atmosphere has only 1-12000th part of the density which it has upon the surface of the earth. The air is therefore as rare as in the artificial vacuum of the best air-pump. Hence, there is no reason to believe that the atmosphere extends beyond the distance of 45 miles. This may appear an amazing thickness, but it dwindles to a small ring when compared with the earth's diameter, of which it forms only the 1-177th part. Thus, in a globe

Atmospheric air is very light. One cubic inch weighs (.305 gr.) about 3-10ths of a grain, and when compared with water, its mean density is as 1 to 828.* It is highly elastic, and is capable of being condensed to a very small bulk, but on the removal of the pressure, it immediately expands. It is what chemists call a permanently elastic gaseous body; for no degree of pressure or cold combined, has yet sufficed to bring it to a liquid state. Mr. Perkins subjected it to a pressure of 800 atmospheres†, or 12,000 pounds on the square inch, but it still remained gaseous. More recently Mr. Faraday has submitted oxygen, one of the main constituents of the air, to a pressure of 58·5 atmospheres, or 877 pounds on the square inch; and at the same time cooled it to 140° below the zero of our thermometer, or 172° below the freezing point of water, but it still remained a *gas*. The degree to which air may be condensed is always directly as the pressure: thus, with a pressure of 800 atmospheres, 800 cubic inches are made to occupy the space of one cubic inch; and on the removal of this pressure, there is an immediate expansion to the original bulk. This will explain the effect of condensed air in the ordinary air-gun.

Like all material bodies, air possesses extension and impenetrability. It has *weight*, *i.e.*, it gravitates to the earth; and the weight or pressure of the atmosphere has a very important influence in physics and meteorology. The weight of the atmosphere, or the force with which a column of it presses upon a given area, is accurately determined by the barometer. In a mean condition, the pressure of the air is equal to sustaining a column of mercury thirty inches high. If we consider them to be *cubic* inches, the pressure of such a column will be exerted on an area of a square inch, and as thirty cubic inches of mercury weigh about fifteen pounds, so it follows that the pressure exerted by the lower

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thirty-six inches in diameter, the proportionate thickness of the atmosphere, or the aerial ocean, would be no more than *one-fifth of an inch!* For a comparison of the actual extent of the atmosphere with the heights of the loftiest mountains in the world and the depth of sea, see Plate VIII.

* One thousand cubic inches of air weigh 304·9 grains, and the same bulk of distilled water weighs 252525 grains. Hence, 304·9 : 252525 :: 1 : 828.

† An atmosphere is equal to fifteen pounds pressure on a square inch, for a reason which will be presently stated.

strata of air, is equal to fifteen pounds on every square inch of surface, whether of the earth, or of the bodies situated upon it.* This is equal to the enormous amount of 2216 pounds, or nearly a ton on every square foot.† From its ready condensibility, the lowest strata of air are compressed into a very small bulk compared with those in the upper regions. Thus, although the atmosphere extends forty-five miles, it loses one half of its density at three and a half miles, or at about one-fifteenth of its height from the surface of the earth, — the barometer at this elevation sinking to fifteen inches.

Although the atmosphere is the common receptacle of all the gases and vapours which emanate from the surface of the earth and sea, yet it is on the whole remarkably uniform in its composition. Thus, all over the earth, on the loftiest mountains as well as in the deepest mines, it is found to be composed chiefly of four different substances:—oxygen, nitrogen, carbonic acid, and aqueous gas or vapour in an invisible form. The average proportions of these bodies are by volume, oxygen 21 parts, nitrogen 77·5 parts, aqueous gas 1·42 parts, carbonic acid 0·08 parts. As these bodies slightly differ from each other in density, oxygen and carbonic acid form rather more by weight than by volume, while nitrogen and aqueous gas form rather less. These gases are not chemically united to each other; they are merely diffused or mixed mechanically, but owing to a remarkable and special property of gases, they tend to spread equally throughout the atmosphere, and do not individually obey the laws of gravitation. Carbonic acid, the heaviest of the four, has been found in air at an elevation of 20,000 feet*; and nitrogen and aqueous gas, the lightest, are found in air at the bottom of the deepest mines of Sweden and Bohemia. The most astonishing fact is the uniformity of its composition in different places and at different times. Thus, air taken from the summits of the Alps and Andes, from the surface of the Caspian Sea, the sandy deserts of Arabia, the islands of the Polar Sea, and from the greatest height to which man has ascended in a balloon (23,000 feet), has been found to yield from 20 to 21 parts per cent. of oxygen, and from 80 to 79 parts of nitrogen, including in these weights the average proportions of the other constituents.†

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* If the earth were covered with a layer of quicksilver *thirty inches* high, the pressure would be exactly equal to that now exerted by the air, which is *forty-five miles* high; and from the relative densities of air and water, a stratum of water 32 feet in depth, would exert a corresponding pressure on the earth's surface.

† The body of a man is calculated to have an area of about fifteen square feet. The pressure exerted upon it is therefore equal to 33,240 pounds, or nearly fifteen tons. This pressure is equal on every side, and inside as well as outside, hence it is not perceptible. The thinnest bladder filled with air and tied, weighs the same whether full of air or empty, and is submitted on its exterior to a pressure of many hundreds of pounds; but the air which it encloses being under the same amount of pressure as that which is on the outside of it, it is neither torn nor rent —in this respect resembling a sheet of the thinnest paper immersed in water. So long as the water presses above and below, the sheet of paper preserves its cohesion; but if the water pressed only on one side, it would be immediately destroyed. By reason of this pressure, air penetrates into all liquids and all porous solids. Water and even mercury contain it. Cork owes its buoyancy to it, for the specific gravity of cork deprived of air is half again as great as that of water.

The properties of air are chiefly dependent upon oxygen. It is this gas which supports animal and vegetable life, and through which the great chemical changes on the surface of the earth are carried on: but the healthiness or unhealthiness of different places are not at all dependent upon the relative proportion of oxygen. The most pestilential air may contain the same amount of this gas as the most wholesome. The insalubrity of places is rather owing to the undue admixture of other noxious exhalations with the proper constituents of the air. These act like aerial poisons: they abound in the swampy jungles of tropical climates.

It is remarkable that the air contained in water, whether spring, river, or sea water, differs in composition from that of the atmosphere. The proportion of oxygen sometimes reaches thirty-four per cent., and this renders the water well fitted for the respiration of fish. Carbonic acid is also more abundant in this air, thus rendering it better adapted for the growth of water-plants.‡

While the proportions of oxygen and nitrogen in air are not subject to any marked change, those of carbonic acid and aqueous gas are continually varying. Carbonic acid is more abundant in dry than in wet weather, at night than during the day, and in summer than in winter. Aqueous gas is always varying, according to fluctuations of temperature—the greater the heat, the greater the quantity which is evaporated into the air, and *vice versâ*. The proportion of this gas is not influenced by the pressure of the air; so that at whatever height the barometer may stand, provided the temperature be unchanged, there is the same amount of aqueous gas in a given bulk of air.

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* In 1829, the writer detected the presence of this heavy gas in the air on one of the summits of the chain of the Great St. Bernard in the Alps, at the height of 10,000 feet above the sea-level.

† Dr. Dalton found that the proportion of oxygen was somewhat less than the average in air taken from the summits of the Cumberland mountains.

‡ Twenty-two gallons of spring water (= 5000 cubic inches,) give 100 cubic inches of air, consisting of oxygen 34·2, nitrogen 55·8, carbonic acid 10.

It is an important question not yet solved, whether, over long periods of time, any material changes take place in the chemical composition of air. Some eminent philosophers have asserted, that the great supporter of life, oxygen, is being slowly consumed, and that the atmosphere is gradually becoming deteriorated; so that in the long lapse of ages it will be rendered unfitted to support animal or vegetable existence. It is consolatory to know, however, that if no facts can be brought against this view, none that are satisfactory can be advanced in support of it. The means of determining with accuracy the composition of the air have not been known to philosophers for more than half a century; and so far as experimental researches within this period will allow us to form a judgment, the results are decidedly adverse to the view, that the proportion of oxygen is undergoing diminution.*

The atmosphere possesses a blue *colour*, not perceptible in small quantities, but plainly evident when we look at it in bulk. Hence, the colour of the sky is blue. This is due to the reflection of the blue rays of light by the particles of mixed gases of which the atmosphere is composed. The blue colour is most strongly marked in the zenith, because there is in this direction, a smaller amount of opaque vapour for the light to traverse. The eye here receives the colour from a column of forty-five miles in elevation ; but on clear days the blue colour of the atmosphere is well brought out by distant mountains, which acquire this tint from the strata of air interposed between them and the eye, often as strongly as if they were seen through a thin plate of pale blue glass. That a cubic foot, or a hundred cubic feet, of air have no perceptible colour, is no objection to this view ; for it is only in vast quantities of material bodies, that colour is often brought out. A thin layer of glass is colourless, a thick plate is perceptibly green, especially at the edges ; one grain of sand possesses no colour, but a collection of myriads of grains on the sea-shore, gives to the mass a brown tint. As a more apposite illustration we may refer to the colour of the waters of the ocean. These are of a rich blue when we look upon a column, or through a space of some thousands of fathoms ; but a cubic foot collected in a glass vessel is as colourless as ordinary spring water.

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* The atmosphere was analysed in 1805 by Guy Lussac and Von Humboldt. They found it to consist of 21·006 of oxygen, and 78·994 of nitrogen, per cent. This is, perhaps, the earliest analysis upon which reliance can be placed. In the year 1822, the air was again analysed by M. Despretz, in three different experiments, and the *mean* of these experiments corresponded *exactly* with the result obtained by Guy Lussac and Humboldt seventeen years before. The writer subjected the air to analysis in October 1841, and the mean result of several experiments in which the fluctuations were small, was 20·8 oxygen, and 79·2 nitrogen. These slight differences need not be considered. In a period of *thirty-six years* the air had undergone no perceptible change in its chemical constitution.

One important consequence follows from this reflection of light by the atmosphere in bulk. While the sun is above the horizon, it tends to diffuse equally the light of day. Without the atmosphere, all objects would be in sharp light and shadow, and the sky would appear colourless, or black, from there being no medium to reflect and diffuse the light. It is said that travellers, on the summits of lofty mountains, have perceived this blackness of space, and even the stars at noon-day. There is no proof, however, that the reflecting powers of the atmosphere are limited to the lower half, which these statements would imply. As a matter of personal experience, the writer can state, that having been on several occasions in the Alps, at an elevation of 10,000 feet above the level of the sea, the only effect observed by him was, that in the zenith the blue appeared purer and deeper ; but he has seen it equally deep from the level of the sea, after heavy showers of rain, and after a large portion of the humidity of the air had been deposited, the atmosphere had thus become partially cleared.*

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* There is a curious phenomenon connected with the atmosphere, which has given rise to much speculation. This is the *Mirage*. In the hot and sandy deserts of eastern countries, distant objects sometimes

Space.—What exists beyond the atmosphere, *i. e.*, in that space in which the planets revolve around the sun? Does any medium fill up the interval of 95,000,000 of miles extending from the earth to the sun, or is it void? It was formerly supposed to be a *vacuum*, as it was otherwise considered by philosophers that not only would the revolution of the earth upon its axis be impeded, but its progress in its orbit around the sun, would in time become sensibly retarded by the friction of any medium, although infinitely lighter than air. But, as from the earliest astronomical records,—from the days of Hipparchus, a period of 2000 years,—there has been no perceptible alteration in the length of the day or year, it was inferred that the earth could have experienced no resistance in its progress; and that, as the name implies, space was a void or vacuum. That there is utter darkness appears probable, from there being no medium, even so attenuated as the atmosphere, to reflect light; that a most intense cold must prevail in this vast region, the extent of which the mind of an astronomer can hardly grasp, is proved by observed facts connected with the temperature of the earth; but the view latterly adopted by scientific men from effects of an unexpected kind connected with cometary bodies is, that all space is actually filled with a fine attenuated matter, the exact nature of which it is impossible to define and difficult to comprehend. As this subject is one of absorbing interest in its relations to astronomy, it may admit of a brief exposition.

From the laws of matter, elsewhere described (Chap. II.), it follows that if a body in motion meet another at rest, there is a certain amount of motion lost, according to the relative densities of the two. If a ball of lead be fired from a gun, it may go for a thousand feet without having its motion perceptibly retarded by the air; but for gravitation it might be carried entirely away from the earth apparently with undiminished velocity. If we substitute for the lead a ball of cork, its course is speedily arrested, not merely by gravitation, but by the resistance presented to its progress by the air. If in examining the effect of motion on the ball of lead

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appear to be raised above the level of the ground, and to float in the atmosphere. Occasionally there are inverted images of mountains, trees, and buildings, presenting the appearance of reflections from water. Hence, travellers in the open desert have thought that they were on the borders of a vast lake; but this appearance entirely vanished as they approached the objects. In the Straits of Messina the images of buildings and streets have been seen inverted in the air; and to these objects the name of *Fata Morgana* has been given. These remarkable effects are owing to the unusual refraction and reflection of light by strata of air of unequal temperatures. They are commonly seen in hot countries towards evening after a sultry day, and while the air is quite calm. A wind entirely destroys them, by causing the rapid diffusion of the unequally heated strata of air. This phenomenon has also been witnessed in the Arctic regions. By causing the inversion of the peaks of rocks and mountains, it has often given a completely castellated appearance to the coast of Greenland. It has also brought into view ships and other objects out of direct vision. In 1822, Captain Scoresby saw in the air, the inverted image of a ship, and identified it as that of his father's, although it was at the time thirty miles distant, and actually below the horizon!

only, we attempted to infer the existence of a resisting medium on the earth, we should probably be led to deny it: there would at least be no proof of it, because there would be no perceptible retardation of the moving body. So it is with the earth in space: as long as philosophers looked to the motion of the *earth* only, there was no proof of any matter surrounding it, or occupying the space beyond. But on examining the motion of a light cometary body, well known as Encke's comet, this was found to be sensibly retarded in its progress; and its retardation could be accounted for in no other way than by inferring that space is filled with a highly attenuated medium capable of offering a certain degree of resistance to its progress. This comet is itself a highly attenuated body; it appears like a mere speck of vapour, through which the stars are plainly seen. Its orbit around the sun is elliptical, and its aphelion is to its perihelion distance, nearly as ten to one. Its period of revolution is remarkably short, being only 1208 days, or three years and one third. It was first seen in 1786, again in 1795, in 1805, and 1819. Encke proved that it was the same comet which appeared in these different years, and hence it received his name. Its return was calculated for 1822; but on comparing the calculated with the observed places, Encke could only explain the difference by supposing the existence of a resisting medium beyond the atmosphere. It was again observed in Europe in 1825 and 1828, and the absolute amount of retardation was then determined.* It is slight, but still admits of calculation; and from its discovery up to the present time it has sufficed to diminish the time of its revolution round the sun by about *two days*, so that the comet is now ten days in advance of the place which it would have reached had there been no resistance. This may appear paradoxical, but it must be considered that, while the resisting medium makes it move more slowly, the comet is more rapidly drawn towards the centre of attraction, and it thus makes a revolution in a shorter path. The comet thus gains more in its progress round the sun than it loses by the diminution of its velocity. As we know nothing of its mass, it is impossible to calculate what comparative amount of resistance will be sustained by each planet of our system, or how many centuries must elapse before the effect of this retarding medium may become perceptible to the inhabitants of the earth. However small the amount of retardation may be, it must in the end stop the revolutions of all the planets. But it is by no means impossible that there may still be some source of compensation yet undiscovered; for all that science has taught us concerning the solar system, tends to prove that stability is the great character which the Creator has stamped upon the universe.†

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* Whewell's Bridgewater Treatise, 195.

† Newton has endeavoured to show how small the resistance of the medium must be, if it exist. The result of his calculation is, that if we take the density of the medium to be that which our air would have according to the present laws of decrease in density at 200 miles from the surface of the earth, and assume that the planet Jupiter (which has about one-fourth the density of the earth) moves in such a medium, he would in a million of years lose less than a millionth part of his velocity. Encke's comet, according to the result of the observations already made,

WINDS.—One property of the atmosphere yet remains to be considered. When heated, it expands and becomes considerably lighter, so that it ascends, until by cooling in its passage through the upper strata of air, it has again passed into a state of equilibrium. The amount of expansion which air undergoes by raising its temperature, has been accurately determined. It is equal to 1–480th part of its bulk for every degree of heat added between the temperatures of freezing and boiling water (32° and 212°). Thus 480 parts of air at 32°, become 481 at 33° and 508 parts at 60°.* It is chiefly owing to this expansion, produced by heat, that the phenomena of winds are due; for whenever a certain portion of air becomes heated, it is rendered lighter and rises into the atmosphere, while cold air rushes in to supply its place. This phenomenon continues until an equilibrium of temperature is restored. In other words, winds owe their origin to the heat of the sun; this heat acting upon some part of the air causes it to expand,—it becomes lighter, and consequently it must ascend; while the surrounding air, which is more dense and heavy, will press forward towards the place where it is rarefied. Upon this principle, we can easily account for the *Trade winds*, which blow constantly from east to west within the tropics; for when the sun shines perpendicularly on any part of the earth, it will heat and rarefy the air in that part, and cause it to ascend; while the adjacent air will rush in to

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will lose in ten revolutions, or thirty-three years, less than 1·1000th of its velocity; and if this law were to continue, the velocity would not be reduced to one half of its present amount in less than seven thousand revolutions, or twenty-three thousand years! (*Whewell.*) These calculations assume that there is no compensation for the apparent irregularities. As the law of gravitation was not discovered until after the lapse of 5000 years, it is by no means impossible that within this or a shorter period of time, the ingenuity of man may lead to the discovery of some law affecting the motion of the planets and comets, sufficient to counteract the slight effects produced by the existence of a resisting medium.

* It is thus demonstrated: 100 cubic inches of air at 32° expand to 137·5 cubic inches at 212°. The increase therefore is $\frac{37 \cdot 5}{100}$ths of the original bulk. The number of degrees between 32° and 212° being 180, in order to ascertain the effect or increase of bulk produced by each degree, it is necessary to divide this fraction by 180, and $\frac{37 \cdot 5}{100} = \frac{75}{200}$ and $\frac{75}{200} \div 180 = \frac{75}{36000}$ or $\frac{1}{480}$.

supply its place, and, consequently, will cause a stream or current of air to flow from all parts towards that which is the most heated by the sun. But as the sun, with respect to the earth, moves from east to west, the common course of the air will be from east to west; and, therefore, at or near the equator, where the mean heat of the earth is the greatest, the wind will blow continually from the east; but on the north side of the equator, it will decline a little to the north, and, on the south side of the equator, it will decline to the south. If the earth were covered with water, the motion of the wind would follow the apparent motion of the sun, in the same manner as the motion of the water would follow the motion of the moon; but, as the regular course of the tides is changed by the obstruction of continents and islands, so the regular course of the winds is changed by high mountains, by the declination of the sun towards the north and south, by burning sands which retain the solar heat, by the falling of great quantities of rain, which causes a sudden condensation or contraction of the air, and various other causes. Thus, according to Dr. Halley, between the 3rd and 10th degrees of south latitude, the south-east trade-wind continues to blow from April to October; during the rest of the year the wind blows from the north-west; but between Sumatra and New Holland this *monsoon* * blows from the south during our summer months; it changes about the end of September, and continues in the opposite direction till April.

Over the whole of the Indian Ocean, to the northward of the third degree of south latitude, the north-east trade-wind blows from October to April, and a south-west wind from April to October.† From Borneo, along the coast of Malacca, and as far as China, this monsoon in our summer blows nearly from the south, and in the winter from north by east. Near the coast of Africa, between Mosambique and Cape Guardafui, the winds are irregular during the whole year, owing to the different monsoons which surround that particular place. Monsoons are likewise regular in the Red

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* The regular winds in the Indian Seas are called *monsoons*, from the Malay word *moosin*, which signifies "a season." (Forest's Voyage, p. 95.)

† The student will find these winds represented on Adams's globes, by arrows having the barbed points flying in the direction of the wind, as if shot from a bow; and, where the winds are variable, these arrows seem to be flying in all directions.

Sea; between April and October they blow from the north-west, and during the other months from the south-east, keeping constantly parallel to the Arabian coast.*

On the coast of Brazil, between Cape St. Augustine and the Island of St. Catherine, from September to April the wind blows from the east or north-east; and from April to September it blows from the south-west; so that monsoons are not altogether confined to the Indian Ocean.

On the coast of Africa, from Cape Bajador, opposite to the Canary Islands, to Cape Verd, the winds are generally north-west; and from hence to the Island of St. Thomas, near the equator, they blow almost directly on to the shore.

In all maritime countries of any considerable extent, between the tropics, the wind blows during a certain number of hours from the sea, and during a certain number from the land; these winds are called sea and land breezes. During the day, the air above the land is rendered hotter and more rare than that above the sea; the cold sea-air therefore flows in upon the land, and supplies the place of the rarefied air, which rises into the atmosphere; as the sun descends, the rarefaction of the land air is diminished, and an equilibrium is restored. As the night approaches, the air over the land becomes more cooled by radiation than that over the sea. Under these circumstances it happens that a land breeze blows towards the sea.

The Cape of Good Hope is famous for its tempests, and the singular cloud which accompanies them: this cloud appears at first only like a small round spot in the sky, called by the sailors the Ox's Eye, and which probably appears so minute from its exceedingly great height.

In Natolia, a small cloud is often seen, resembling that at the Cape of Good Hope, and from this cloud a terrible wind† issues, which produces similar effects. In the sea between Africa and America, especially at the equator and in the neighbouring parts, tempests very often arise, and are generally announced by small black clouds. The first blast which proceeds from these clouds is furious, and would sink ships in the open sea, if the sailors did not take the precaution to furl their sails. These tempests seem to arise from a sudden rarefaction of the air, which produces a kind of vacuum, and the cold dense air rushes in to produce an equilibrium.

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* Bruce's Travels, vol. i. chap. iv.

† This wind seems to be described by St. Paul, in the 27th chapter of the Acts, by the name of the Euroclydon.

HURRICANES, which arise in tropical countries from similar causes, have a whirling motion leading to the overthrow of ships, trees, or houses. A calm generally precedes these destructive tempests, and the sea then appears like a piece of glass; but, in an instant, the fury of the winds raises the waves to an enormous height. When, from a sudden rarefaction, or any other cause, contrary currents of air meet in the same point, a whirlwind is produced.*

A very ingenious theory, regarding storms, has been propounded by Colonel Reid. According to this gentleman, every storm may be regarded as a mighty hurricane or whirlwind, the wind blowing constantly in one direction in a great circle, the diameter of which in the open ocean is from 1000 to 1800 miles. This vast whirlwind is itself in motion, progressing with rapidity along a curve approaching to a parabolic form, the circles expanding as they advance from the point at which the storm begins to be felt. The rotatory motion in the northern hemisphere is from east to north, west, south and east; and in the southern hemisphere in a contrary direction. The progressive motion of the hurricane varies from seven to twenty miles an hour; while the rotatory motion, that of the true hurricane, is from 60 to 70, and even 100 miles per hour. He has arrived at these conclusions from the examination of the relative position of ships which have encountered a heavy storm at or about the same periods of time at great distances from each other. Some of these vessels scudded and ran in the storm for days,—some by lying to got almost immediately out of it, *i. e.* it passed them; while others, by taking a wrong direction, went into the heart of it, foundered, and were never heard of more. Others, by sailing right across the calm space, met the same storm in different parts of its progress,—the wind blowing in opposite directions,—and it was considered and spoken of as two storms which had been encountered; while others by cruising about within the bend of the curve, but beyond the circle of the great whirl, altogether escaped the storm which had been for days raging on all sides of them. These facts are of great practical importance in navigation, but they yet require further investigation before the theory can be fully received.

It is remarkable that, at St. Helena, where Captain Sabine found the magnetic intensity least, there are no violent storms. The line of least magnetic intensity is probably the true Pacific Ocean.

The force of the wind upon a square foot of surface is nearly as the square of the velocity; that is, if on a square board of one foot in surface, exposed to a wind, there be a pressure of one pound, another wind, with double the velocity, will press the board with a force of four pounds, &c. The following table, extracted from the Philosophical Transactions, shows the velocity and pressure of the winds, according to their different appellations.

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* Two currents of air, or water, in motion, passing each other in opposite directions, always produce a revolving motion of the air or water at the point where they meet.

Velocity of the wind.		Perpendicular force on one square foot in pounds avoirdupois.	Common appellations of the winds.
Miles in one hour.	Feet in one second.		
1	1·47	·005	Hardly perceptible.
2	2·93	·020	Just perceptible.
3	4·40	·044	
4	5·87	·079	Gentle pleasant wind.
5	7·33	·123	
10	14·67	·492	Pleasant brisk gale.
15	22·00	1·107	
20	29·34	1·968	Very brisk.
25	36·67	3·075	
30	44·01	4·429	High winds.
35	51·34	6·027	
40	58·68	7·873	Very high.
45	66·01	9·963	
50	73·35	12·300	A storm or tempest.
60	88·02	17·715	A great storm.
80	117·36	31·490	A hurricane.
100	146·70	49·200	A hurricane that tears up trees, and carries buildings, &c. before it.

From later experiments it has been inferred, that wind of a mean intensity has a velocity of 10·6 feet in a second, or 7·2 miles in an hour; while a very violent hurricane has a velocity of 128 feet in a second; or a rate of not quite 80 miles in an hour.

CHAPTER IX.

Of Vapours, Fogs, and Mists, Clouds, Dew and Hoar Frost, Rain, Snow and Hail, Thunder and Lightning, Falling Stars, Ignis Fatuus, Aurora Borealis, and the Rainbow.

1. VAPOURS.—Evaporation is continually taking place from the earth and sea; and the amount of vapour which is carried up depends upon temperature, and the motion and dryness of the air. The higher the temperature, the more rapid the motion, and the dryer the air, the larger the quantity of water which is evaporated.* The vapour which thus passes into the air is invisible, except when we look over an extent of surface; it then appears like a white mist in the horizon. If the air be saturated with vapour, and then by a slight fall of temperature it becomes cooled, a large portion is precipitated in the form of a distinctly visible mist or fog.

2. FOGS are commonly spoken of as terrestrial clouds: they are precipitated aqueous vapour, but the particles are in so finely divided a state as not readily to cohere to form water. Fogs are especially prevalent in low situations where water collects, and in or near rivers, lakes, or seas. They occur most readily at those periods of the year when there are sudden and rapid changes of temperature combined with great humidity, as in spring and autumn. If a heavy fall of rain, with a large amount of evaporation, be followed by a low temperature, a fog is produced by the partial separation of the aqueous vapour in a visible form. They are most commonly seen in the morning or evening, for the same reason. The fogs of inhabited towns are mixtures of aqueous vapour with smoke; they contain ammonia and other gases,

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* At a temperature of 45° from an area of water of 28·29 square inches, and in a perfectly dry atmosphere, there are evaporated 1·36 grains of water: — at a temperature of 75°, the quantity evaporated in the same time is 3·65 grains. The effect of motion is seen in the following amounts of evaporation from the same area.

	Calm.	*Breeze.*	*High Wind.*
45°	1·36 grains	1·75	2·13.
75	3·65 —	4·68	5·72.

These results are based on Dr. Dalton's researches. Water evaporates at all temperatures, even at and below 32°. Ice and snow give off vapour.

which have a strong tendency to diffuse themselves. A *mist* is aqueous vapour still more condensed by cold—*i. e.* a fog passing into fine rain. The fog which always exists off the bank of Newfoundland arises from the mixture of the warm air brought by the Gulf stream, with the cold air brought by the currents of the Arctic Seas. These currents meet off the bank, and the warm air of the stream suddenly meeting with a large body of cold air parts with a portion of its vapour, and thus produces perpetual fogs. The blighting and suffocating wind, known in the Mediterranean states under the name of the *Scirocco*, is a south-easterly wind which passes over the arid sands of Arabia and Egypt. It thus becomes thoroughly dried, and in traversing the Mediterranean, by its rapid motion, dryness, and high temperature, it takes up a large amount of vapour, which is again precipitated in a thick hot mist when it blows over a colder surface, as in Greece, Italy, and other parts of the Mediterranean. By the exhaustion which it produces from heat and humidity, it renders individuals almost powerless.

Fogs in this country are observed to be very prevalent with easterly winds. This arises from the warm wind becoming saturated with vapour in traversing the German Ocean, which is again partially precipitated when it meets the cooler surface of the earth.

3. CLOUDS.—When the vapour rises to a certain height in the atmosphere, a partial condensation takes place, and a cloud is produced. Whatever cools the air will suffice to cause a separation of vapour. Thus clouds are often produced by the meeting of two currents of air of different temperatures. In mountainous districts, from the greater coldness of the earth in these situations, clouds are abundantly formed. It is singular that the cloud does not take a well-defined form, until it has risen to a considerable height above the surface. It then spreads out into a sheet, or layer, which is called a *stratus*, thick in the centre, when seen sideways, and terminating apparently in two sharp points. It would appear as if a certain elevation were necessary to allow the minute globules, or spherules of water, to coalesce without passing to the state of water. As the stratus ascends, it becomes rounded at the top and more globular in its form, thus producing the cloud called *cumulus;* which is always perfectly flat at the lower part, being brought to a horizontal line by the greater density of the stratum of air on which it

reposes. The fine pencil-like clouds which are seen at a great elevation in thin streaks, commonly in the zenith, are called *cirri.** Clouds differ much in their elevation: the stratus is generally near the surface, varying from 800 to 1000 feet; the cirrus reaches a height probably of from two to three miles. The cumulus occupies an intermediate elevation: but it has been seen above a height of 10,000 feet. The shapes of clouds change materially, according to the aspect in which they are regarded. When a cloud is approached, its well-defined margin is entirely lost, and it has all the characters of a fog, or even of a damp mist. The aqueous vapour rushes by with astonishing rapidity, and the time occupied in its passage shows that some clouds must fill some thousands of cubic yards of space. A peculiar smell has been perceived in the vapour of a cloud even at a great elevation above the sea-level. This may arise from the attraction well known to exist between aqueous and other vapours floating in the atmosphere. Clouds have sufficient body to be well adapted for the reflection of light, and the tints reflected from them by the rays of the rising and setting sun, refracted by the atmosphere, are of the richest description.

4. DEW.—When the earth has been heated in the day-time by the sun, it will during the night throw off a portion of the heat it has so acquired. This is what is called heat of radiation, because it is thrown off or radiated into the atmosphere. The extent to which the diminution of temperature takes place depends greatly upon the aspect of the sky: on a clear night it goes on more rapidly, and to a much greater extent, than when the sky is overcast or cloudy; hence in clear nights there is a much greater deposition of dew than in cloudy weather. As an explanation of this, it may be stated, that *dew* is not a kind of fine rain showering down upon the earth from above, but that it depends upon the slow deposition of moisture from the atmosphere by the simple process of cooling, and is, in its formation, precisely similar to what happens when a glass of iced water is brought into a warm room in summer; the coldness of the surface of the glass abstracts the heat from the vapour in the air around it and causes its condensation in the form of water, which is

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* *Stratus* from the Latin, signifying a layer; *cumulus*, a heap, and *cirrus*, a lock of hair. The three other forms of clouds are compound, i. e. *cumulo-stratus*, *cirro-stratus*, and *cirro-cumulus*.

deposited exactly like dew upon the outside of the vessel. The most essential condition for the production of dew is, that a body should have its temperature considerably lower than that of the surrounding air. Thus shrubs, under the shelter of a balcony, never have dew deposited on them; and on a cloudy night there is no dew because the clouds reflect back the heat to the earth. When dew freezes, it produces hoar-frost.

5. RAIN.—Evaporation never takes place without the evolution of electricity. Each minute globule, or vesicle of water holds a portion, and carries it into the atmosphere. The higher it ascends the greater is the intensity of this electricity; and thus clouds always hold a large portion of electric fluid. It is very probable that the minute globules of which the cloud is constituted, are prevented from coalescing to form water by the electrical repulsion existing between them. When, from any cause, this electrical state is withdrawn, as by its slow and silent evolution from changes in the condition of the atmosphere, — the spherules of water unite and form globules of rain. Some cubic miles of cloud are thus often converted to water, — the clouds losing their well-defined outline, and blending together in a confused mass, which meteorologists call the *nimbus*. The descent of the clouds nearer to the earth, owing to a diminution in the pressure of the atmosphere, is probably attended with a partial loss of electricity, so that the particles which constitute the cloud no longer repel each other with the same force; and the fall of rain will be slow or rapid according to the rapidity with which this electric tension of the particles is destroyed. When clouds approach elevated mountain chains, rain is a frequent consequence; — the electric fluid is probably then drawn off by the peaks, and the cloud is partially or wholly condensed to the state of water. Mere cooling is not sufficient to cause the conversion of clouds to rain; for we find clouds existing at elevations where the thermometer is at or below the freezing point of water. Rain falls in drops of a spherical form, varying greatly in size; it is estimated that their velocity is in the duplicate ratio of their diameters. More rain is collected on a given area at the base of a building than at its summit:— thus the quantity of rain which fell in one year on the top of York Minster amounted to 14·9 inches, while the quantity collected by a similar instrument on the ground varied from

19·8 to 25·7 inches. Hence, any instrument to measure the quantity of rain, should always be placed on the ground. This difference has been ascribed to the drops of rain uniting during their descent; but it is more probably due to the effect of eddies and currents of air above the surface diverting a portion of the water from the receptacle.

The amount of rain which falls to the earth decreases as we recede from the equator and approach the poles. The annual average fall of rain, under the tropics, is 95 inches; in Italy, 45 inches; in England, 30 inches; in North Germany, 22·5 inches; and at St. Petersburgh, only 17 inches. The following table of the annual amount is thus given by Professor Berghaus,

Under the tropics of the New World . . .	115	inches.
„ „ „ Old World . . .	76	—
Within the tropics generally	95·5	—
Temperate zone of the New World (U.S.)	37	—
„ „ „ Old World (Europe)	31·75	—
Average within the temperate zone . . .	34	—

From Saint Domingo to Finland the annual amount decreases from 150 to 13 inches. The greatest annual amount of rain, hitherto observed, was,

Mahabaleshwar, Western Ghauts, lat. 18° N.	301·5	inches.
Matouba, Guadaloupe, lat. 16° N.	285·75	—

The number of rainy days are observed to increase with the latitude, or the distance of a place from the equator, *i. e.* the rainy days are fewest where the fall of rain is greatest. Between the tropics the greatest quantity falls while the sun is at the zenith, *i.e.* at the season corresponding to our summer, while north of the tropics the greatest amount is observed to fall in winter. If the quantity of rain which falls yearly in these latitudes be indicated by 100, the relative amount, according to the seasons, will be as follows:

Winter	50·6	per cent.	
Spring	16·3	—	
Summer	2·8	—	
Autumn	30·3	—	(*Berghaus.*)

The quantity of rain decreases as we recede from coasts to the interior of continents, and as we ascend from low plains to elevated lands (high table lands); but it increases in ascending from plains to the slopes of steep and rugged mountain chains. In the temperate zones of both hemispheres, more rain falls on the western than on the eastern coasts. Within the tropics the eastern coasts are the most humid, owing to the vapour carried by the trade winds. An enormous amount of rain falls along the whole of the western shores of Patagonia. At Cape Horn the quantity collected in forty-one days was equal to 153·75 inches. Incessant westerly winds, bringing with them the vapour of the Pacific Ocean, prevail around this, the Cape of Storms; and the ruggedness of the lofty mountain chains favours the precipitation.

The influence of rain on climate depends not merely on the quantity which falls annually, but on the number of days in which it falls. It is remarkable that there are some extensive districts in the world where rain is never known to fall, and in others it falls only at very long intervals. The most extensive of these, according to Berghaus, is that which stretches from the borders of Morocco through the deserts of Africa and Arabia, Iran, Persia, into Beloochistan, occupying a space of 80° of longitude by 17° of latitude. Its area is equal to 3,000,000 of square miles. Another rainless district comprises the Great Desert of Gobi, in the table land of Thibet, and part of Mongolia. It contains 2,000,000 of square miles. Very little rain falls in Guatemala, California, and Lower Peru.

6. SNOW consists of frozen aqueous vapour. When closely examined, a flake of snow is found to be made up of minute crystals of ice of a prismatic shape, intersecting each other in all directions. When the freezing takes place slowly, under intense cold, the crystals assume the shape of a star, formed of six prisms radiating from a centre. Snow is only seen at a considerable elevation within the tropics. In the western part of the Old World, the equatorial limit of the fall of snow corresponds to the parallel of 30° north latitude, so that it includes the whole of Europe. In the southern hemisphere its limit at the sea level is 48° south. It increases as we proceed north, and in a direction from west to east.

7. HAIL is formed of masses of water, probably condensed from clouds, and frozen at a very great height in the atmosphere. If the globules of water traverse a sufficiently cold stratum of air, they reach the earth as hail. When the rain is rapidly frozen, the masses are opaque; when more slowly frozen they are translucent, and sometimes of considerable size. Snow, which consists of the fine frozen vapour of the atmosphere, is only seen during winter, or after the prevalence of intense cold. Hail may fall at all seasons, even in the hottest weather; because it depends on the solidi-

fication of water by the cold which uniformly prevails in the upper regions of the atmosphere. The stones vary in diameter, rarely exceeding 1-3d of an inch; but sometimes they are of considerable size, and are capable of producing great destruction by the momentum which they acquire in falling.

8. THUNDER AND LIGHTNING.—All bodies contain electricity, but the presence of this powerful agent is never rendered apparent to us, except when its equilibrium is disturbed; and the slightest causes, such as the friction of bodies, crystallisation, and evaporation, suffice for its evolution. When the natural electricity of a body is disturbed, it is resolved into two kinds,—a *positive* and a *negative* fluid,—each of which repels electricity of the same kind, but attracts that which is of an opposite kind*; just as the north pole of one magnet repels the north, but attracts the south pole of another magnet.

The most accurate researches have proved that *evaporation*† is the great source of atmospheric electricity. The extent to which this takes place has been already considered. In tropical climates it goes on with greater rapidity than in high latitudes; and as the accumulation of electricity is in proportion to the intensity of evaporation, we have, in this, an explanation of the frequent occurrence of storms in warm latitudes. Storms are not common beyond the 75th parallel of latitude, but below the 65th they become frequent, and increase in frequency in proportion as the latitude diminishes. It is remarkable that in Lima, on the western coast of South America, the occurrence of thunder and lightning is unknown. This, it is to be observed, is a rainless district, like the great deserts of Africa, Arabia, and central Asia. Clouds never being formed in these regions, there are no masses of vapour to receive and accumulate the electric fluid.

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* The positive electricity is often called *Vitreous*, because it is excited by the friction of glass; the negative is called *Resinous*, because it is excited by the friction of shell-lac and other resins. Although the effects of the two are, in most respects, similar, they are marked by this difference, that a body charged with one attracts a body charged with the other; and when they have met, no electricity is to be discovered in either body, for the one kind appears to have the power of completely neutralising and destroying the other.

† M. Pouillet has ascertained that the evaporation of pure distilled water is not attended with the evolution of electricity; *i. e.* there is, during its evaporation, no disturbance of the equilibrium. Should the water contain the smallest quantity of saline matter, the electric equilibrium is immediately destroyed by the separation of the water from the salt, under the influence of heat. It need hardly be said that all the waters on the surface of the earth are charged more or less with salt; hence evaporation never can occur without electric disturbance; and let the reader consider from the facts already stated with regard to the enormous surface of the oceanic waters, and the daily amount of evaporation, the extent to which the equilibrium of the electric forces must become daily disturbed.

Philosophers have determined that, in general, during evaporation, the positive or vitreous electricity rises with the vapour, while the negative or resinous remains behind on the evaporating surface. Whence comes electricity? The answer to this is, that all bodies contain it in enormous quantities — if we may speak of *quantity* with respect to an agent which can neither be seen, weighed, nor, in ordinary language, measured. We call it a fluid, but we know not what it is except by its marvellous effects. Faraday has calculated that the quantity of electricity contained in a single *drop* of water, measured by chemical affinity, is equal to that evolved in 800,000 maximum discharges of our largest batteries of Leyden jars; one discharge of which would suffice to kill a good-sized cat! The earth is a vast source of it, but the atmosphere does not contain it except in so far as the aqueous vapour, one of the constituents of the air, may enable the electric fluid to diffuse itself. Dry air is a non-conductor; hence the electricity of evaporation collects in and around the minute spherules of water, of which clouds are composed.* Clouds, are, therefore charged conductors

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* The heavy fall of rain which commonly takes place during a thunder-storm tends to saturate the air with moisture, and to render it a better conductor of electricity. The spherules of vapour in the thunder-clouds, by the discharge of their electricities, are probably converted to water, which falls as rain; and it is a remarkable fact, that the rain which first falls in a thunder-storm always contains nitric acid, generally combined with ammonia! The nitric acid is formed by the electric discharge, causing the nitrogen to unite directly to the oxygen of the atmosphere. The ammonia is derived from the atmosphere. As a striking analogy in the effects, although on a widely different scale, it may be mentioned that the spark discharged from an electric machine produces an acid reaction on test paper in moist air; and forms nitrate of potash, or saltpetre, when it is received upon paper holding a solution of caustic potash. Nitric acid is thus proved to be formed even by the artificial spark! Some have accounted for the vast beds of nitre found in tropical countries by the nitric acid thus formed naturally in thunder-storms.

As a singular illustration of the power of moisture to render a body a holding a quantity of electricity in proportion to the previous amount of evaporation, and to their extent, which may sometimes occupy some thousands of acres of space. If the electricity be not too rapidly accumulated in them, it may slowly pass off into the air without producing any very marked effects, forming sheet-lightning, or it may be slowly drawn off by the peaks of mountains, and conveyed again silently into the earth. In philosophical language, the equilibrium may be restored by the meeting and neutralisation of the two electricities. If, however, the accumulation has been vast, and the evolution of the electric fluid, from its high tension, be sudden, then we have, immediately produced, the phenomena of lightning and thunder.

The discharge of the electric fluid to restore the equilibrium may take place between two clouds, — between a cloud and the earth, or any object on the earth. It is remarked that the forked lightning, or that which takes a zigzag course, is generally a discharge between a cloud and the earth. The zigzag course is probably indicative of the different degrees of conductibility in the strata of air. When two clouds contain equal quantities of the same electricity, there is no tendency to a discharge; when they contain opposite electricities, or even unequal quantities of the same, then, supposing them to approach sufficiently near to each other to overcome the resistance offered by the air placed between them, a discharge takes place, and they pass to a state of equilibrium. The earth is commonly negatively

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conductor, it may be mentioned that when Franklin first made the experiment to draw the electric fluid from the thunder-clouds in the upper regions of the air, he did not succeed in procuring any evidence of it from the string of the kite which he employed. A shower of rain fell, the string became wet, and the electric fluid descended immediately. An experiment of this kind is always attended with considerable danger.

According to Professor Daniell, although the atmosphere is not usually charged with electricity so as to produce any marked or visible phenomena, yet it will commonly afford indications of electrical excitement. He states that in calm dry weather, when no clouds are visible, the gold leaves of an electroscope always indicate positive or vitreous electricity, the intensity of which is subject to regular variations, reaching a maximum about seven or eight o'clock in the morning, and falling to a minimum between one and two. In high winds and damp weather, without rain, electrical indications can rarely be obtained; and in cloudy weather, and in times of showers of hail, rain, or snow, they vary much both as to kind and intensity.

electrified, while the clouds hold positive electricity; hence a discharge often occurs between them and the earth.*

The *light* of the electric discharge is *lightning*. It is not owing to any form of combustion like artificial light, but it is the self-luminous character of the electric fluid when in its highest state of tension. It is of a purple, blue, or violet colour, and is illustrated, on a small scale, by the colour of an electric spark from a large machine. The cause of the sound, or thunder, is ascribed to the violent concussion of the air by the sudden passage of the electric fluid. It is imitated on an infinitely small scale by the snap which follows the discharge of a large battery of Leyden jars. It does not arise from any explosion or ignition of inflammable gases, for no such gases exist: there is no rushing of the air into a vacuum, for there is no proof that a vacuum is formed. A vacuum implies the sudden abstraction or removal of a large quantity of matter; but of the occurrence of this there is no evidence. It may be difficult to conceive how an imponderable fluid should, by mechanical force, so strike the air as to produce the loud sound of thunder; but it is just as difficult to understand how it should rend asunder and destroy, in an inconceivably short period of time, lofty buildings, and fuse some of the most infusible substances.† The same principle by which we explain the noise of the electric spark from a machine, equally applies to the explanation of thunder. The difference in the sound of artificially and naturally accumulated electricity, is no greater than that which we might expect from the difference in the relative quantities accumulated, and in the equilibrium which is to be restored by the respective discharges.‡ The repeated claps, or explosions, are probably due to successive discharges from various clouds, approaching each other during the storm, at different distances from the individual; and the rolling may be partly ascribed to the reverberation or echo.

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* The electric fluid possesses a property called *induction*, owing to which one body, highly charged, when sufficiently near to another, containing only its natural amount of electricity, disturbs its electricity and produces in it a state opposite to that which exists in itself. Thus a cloud, highly charged with positive electricity, approaching another cloud in its natural state, or the surface of the earth, renders the parts nearest to it highly negative, by repelling the positive electricity contained in the cloud or earth. Hence a discharge follows.

† The reader need hardly be told that there is no thunderbolt — that these effects do not result from the projection of ponderable matter. They proceed entirely from an imponderable fluid. Thunderbolts, vulgarly so called, are round balls of iron pyrites (a compound of sulphur and iron) laid bare by the washing of the strata after a heavy thunderstorm.

‡ In the explanation of these grand phenomena, we must bear in

Professor Wheatstone ascertained by an ingenious optical apparatus, exposed during a thunderstorm, that "the duration of a flash of lightning is a very minute fraction of the thousandth part of a second;" and a flash has been found, by the known velocity of sound, frequently to traverse a space of nine or ten miles. According to Arago the electric flash lasts only for the millionth part of a second! The velocity of the electric fluid is certainly not less than that of light, *i. e.* about 200,000 miles in a second of time. Hence lightning, however distant, must be seen by a spectator at the very instant at which it occurs. Sound, however, travels much more slowly (see page 51.); its mean velocity at 60° is only 1120 feet in a second: hence the interval between the sight of the flash and the hearing of the thunder is very perceptible; and as there are 5280 feet in a mile, and the time required by sound to travel this distance is equal to 4·71 seconds, so it follows that we may allow the distance of rather more than a mile for the lapse of every five seconds.*

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mind the difference between the puny efforts of art and the vast operations of nature. In comparing the effects of a charged conductor of some thousand acres in extent with one of a few square feet, we must be prepared for great differences in the results. The writer has seen a spark of a charged conductor of a very powerful battery six inches in length; some are described as twelve or fourteen inches. Sparks obtained by deriving electricity from thunder-clouds in the atmosphere, have been ten feet long, and apparently two or three inches in diameter. In a violent storm, the sparks are probably some miles in length, and the effects of the electric fluid are proportionate!

* From the facts collected by Mr. Walker, it would appear that the thunder has been known to follow the flash in so short an interval as *half a second!* The duration of the loudest part of each roll of thunder has been found to vary from twenty to thirty seconds. The interval between the flash and thunder rarely exceeds forty-eight seconds, and this is equal to a distance of about *ten miles.* Beyond this distance it is usually inaudible; although one instance is reported of the interval being equal to seventy-two seconds, or fifteen miles.

On the velocity of lightning, the following experiments which the writer has more than once witnessed, may be related. When we are moving with great rapidity, as in a railway train, at the rate of 40 to 80 feet in a second, near objects appear to lose their form, and to fly past us with inconceivable rapidity, becoming at the same time lengthened, owing to

Thunder may occur without lightning being perceptible, as where it takes place during the day between two clouds, one of which is placed above the other. Lightning may occur without thunder, as where the electric fluid is silently discharged into the atmosphere, on a summer's evening, in long sheets. This lightning is of a reddish colour, and it commonly appears in flashes behind large clouds (*cumulo-strati*); if a crack or fissure exist in the bank of cloud, the appearance of the light from behind has very much that of forked lightning. The thunder-cloud commonly has the

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the duration of the impression produced by them on the retina of the eye. A large rounded pebble is no longer seen as such, but it presents the appearance of a brown streak, six or eight feet in length: all bodies by the side of the road appear to run into parallel lines; just as a stick lighted at one end, when swung round with great velocity, appears to the eye a circle of fire.

If a circular disc of card be painted with the seven colours of the rainbow, and made to revolve, under exposure to ordinary daylight, with great rapidity, the individual colours are entirely lost, and the disc appears of a dirty-white hue. This effect depends on the rapid revolution, and the length of time which the light falls upon it. The whole of the colours are seen in a confused mixture. If the disc make a hundred revolutions in a second, and we see it for the tenth part of a second, it must make ten revolutions while we are looking at it, and the colours will still appear confused. If, however, the light fall upon it for the thousandth part of a second, it is clear that it will only make the tenth part of a revolution in that time, and it will appear to be scarcely moving. If it fall upon it in the ten-thousandth part of a second, or less, it will, for a similar reason, appear to have no motion whatever: and thus, when an artificial discharge of electric light is made in the dark upon such a disc while in rapid revolution from a Leyden jar, it apparently becomes instantly motionless, and all the colours are seen separately and distinctly from each other. Objects seen by lightning during darkness in railway travelling thus appear to be at perfect rest. Nothing, perhaps, can more strongly show, than these facts, the inconceivable velocity of the electric fluid.

It was just now stated that from a calculation made by M. Arago, a flash of lightning does not last longer than the *millionth* part of a second! Admitting that this is only an approximation to the truth, it brings before us the extraordinary quickness of vision; for, while the flash lasts, all objects are visible to the eye, and yet the light whereby they are seen must be reflected from them in an inconceivably short period of time. From a consideration of these facts, the reader will be prepared to understand, that in a thunderstorm during the night at sea, the waves, although in violent motion, appear to be suddenly petrified, or at perfect rest during the lightning-flash; and under similar circumstances on land, the leaves and branches of the trees, although in violent motion from wind, appear to become suddenly still.

m of a *cumulo-stratus*, spreading upwards in a palmated ipe. These thunder-clouds have been observed at all vations, from 3000 to 15,000 feet above the sea-level. mboldt states, that he has seen them enveloping the hest summits of the Andes. He witnessed the effects of htning on one of the rocky pinnacles above the crater of volcano of Toluca, at an elevation of nearly 15,300 feet: t thunder-clouds have also been seen over the lowlands in temperate zone, of a measured vertical elevation of 26,650 t. In some instances, the elevation of the cloud is not ater than 2000 feet. (See Plate VIII.)

9. Falling or Shooting Stars, Aerolites[*], and Ball htning, are names applied to certain *fiery meteors*[†], the gin and nature of which appear to be involved in great scurity. They have of late years attracted the attention philosophers, in consequence of their periodical appearance, vast numbers, generally about the 10th of August, and tween the 12th and 14th of November. The heights at ich they move have been estimated at from 16 to 140 les, and their velocities, which are similar to those of the nets, at from 18 to 36 miles in a second. The course of meteor is generally in a curve from the zenith towards horizon, which it rarely appears to reach. Respecting ir nature little seems yet to be known; for whilst some inent philosophers and astronomers have supposed them be generated in the atmosphere, others have imagined t they were projected from the moon. The prevailing inion of astronomers now is, that they are masses of matter onging to the solar system — circulating independently in ce, and only becoming luminous when they pass into the hosphere. Whether they do or do not accompany the th in its orbit is unknown.

These fiery meteors, when they approach the earth, often rst with a loud explosion, like a clap of thunder, and avy stony substances have been observed to fall from them the earth.

The stony bodies, which are called aerolites, have been served to have a high temperature when found recently er their fall. They vary in size from a few ounces to several tons. They are usually of a rounded form, and always covered with a black crust. When broken, they appear of an ash-grey colour, and of a granular texture, like coarse sandstone. According to one theory they are concretions actually formed in the atmosphere, but in what manner no rational account has yet been given. They are principally composed of iron, and often contain that rare metal, nickel.*

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[*] From ἀὴρ, *the air*, and λίθος, *a stone*.

[†] From μετὰ, *beyond*, and ἀείρω, *I lift up*; being raised above the nosphere.

10. OF THE IGNIS FATUUS, commonly called *Will-with-a-Wisp*, or *Jack-with-a-Lantern.* Sir Isaac Newton, in his Optical Queries, calls this a vapour shining without heat. Various accounts of it may be seen in the Philosophical Transactions. The most probable opinion is, that it consists of a spontaneously inflammable gas, emitted from the decomposition of substances containing phosphorus, in marshy grounds. Dr. Shaw† has described a remarkable ignis fatuus, which he saw in the Holy Land, when the atmosphere

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* Aerolites have been frequently observed to fall after an electrical explosion; hence the name applied to them, *ball-lightning*. The specific gravity of aerolites is about 3·; *i. e.* they are three times as dense as water. The substances of which they are composed are analogous to those which are found in the crust of the earth; they include iron, nickel, cobalt, manganese, copper, chrome, arsenic, tin, potash, soda, sulphur, phosphorus and carbon. The presence of native, or pure metallic iron, gives them a peculiar character. It is singular that they have not been found in a fossil state in the secondary and tertiary strata. It is calculated that no less than seven hundred falls of aerolites take place on the surface of the earth yearly.

The velocity of a falling star or aerolite may be estimated from the fact that, although it describes a large arc at a great elevation, there is often only one streak of light perceptible, from the beginning to the end. This velocity is estimated at 114,000 feet, or rather more than 21 miles in a second! One ingenious view of their nature is, that they are small planetary masses, having their own independent orbits in space, which cut the plane of the ecliptic at that point which the earth reaches in its annual revolution, between the 12th and 14th of November. Humboldt speaks of them as forming part of the rough material of the universe; but the fact that no substance is found in them which does not exist in our planet, tends to favour the presumption that they have a terrestrial origin. As, however, the iron is unoxidised, it is probable that the particles of this metal become aggregated with those of the rare metals, cobalt and nickel, far beyond the regions of the atmosphere, or any medium containing oxygen. It is rare to find a specimen of iron in the earth, except in a state of chemical combination. The diameter of the largest of these meteoric stones has been calculated at from 83 to 2600 feet; that of the smallest planet, Ceres, 70 miles; but two planets, still smaller, are reported to have been recently discovered.

† Shaw's Travels, p. 363.

was so uncommonly thick and hazy, that the dew on the horses' bridles was remarkably clammy and unctuous. This meteor was sometimes globular, then in the form of the flame of a candle, presently afterwards it spread itself so much as to involve the whole company in a pale harmless light, and then it would contract itself again, and suddenly disappear; but, in less than a minute, it would become visible as before, and running along from one place to another with a swift progressive motion, would again expand itself, and cover a considerable space of ground.

Our knowledge of the nature of the *terrestrial* light called ignis fatuus, is very imperfect. It has not yet been accurately observed by one capable of examining it. If, as it is supposed, it proceeded from the escape of phosphuretted hydrogen, it could not move about. Most probably in these cases the fiery appearance has presented itself at intervals, as the gas escaped in bubbles, and the spectators may have thus been led to imagine that it possessed motion. In Persia, and some eastern countries, an inflammable vapour escapes from the earth (naphtha). This is easily kindled, and then continues to burn. In some cases, ignes fatui are nothing more than luminous electricity (from an excessively electrical state of the atmosphere) discharging and fixing itself silently upon pointed objects. In the Mediterranean this appearance is called the FIRE OF ST. ELMO. It is often seen on the masts and points of the yards of ships at sea. The whole subject requires further investigation.

11. OF THE AURORA BOREALIS, OR NORTHERN LIGHTS.* This is an electrical phenomenon which occurs only in high latitudes. It consists of vast sheets of light, appearing towards sunset, spreading upwards and converging towards a point, thus giving the form of a bow. It is seen after sunset, generally towards the north, and is most brilliant in the polar regions, where it often presents the most splendid colours, *i. e.*, yellow, emerald, green, and blood red. The rays of light are continually varying in their colour, brightness, and intensity; but the result is, that the whole of the sky is illuminated; and it has been remarked by polar travellers, that the shadows of men and other objects on the white snow are occasionally seen in the complementary

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* Philosophical Transactions, No. 305. 310. 320. 347, 348, 349. 351, 352. 363. 365. 368. 376. 385. 395. 398, 399. 402. 410. 418. 431. and 433., &c.

colour of that which was predominant in the Aurora. Thus with an intense red light the shadows were green, and with a green light, the shadows were red.

The cause of this phenomenon is now generally admitted to be the discharge of electricity in a highly attenuated medium. The aurora varies in height from 50 to 300 miles above the surface of the earth; and the same aurora shows itself at different elevations, varying in height as well as in intensity. (See Plate VIII.) The aurora is artificially produced by making an electrical discharge into a long glass tube, brought to the state of a vacuum. The electric fluid then spreads through the vessel, with a pale blue or violet coloured light. The average height of the aurora is probably from 100 to 130 miles, — a distance at which no atmosphere can be supposed to exist. Mr. Faraday considers that the phenomenon is due to the discharge, above the atmosphere, of the accumulated electricity in the polar regions. The equilibrium is thereby restored at the equator.

There is a close connexion between this phenomenon and terrestrial magnetism. The bow commonly has a symmetrical relation with respect to the magnetic meridian, and when it appears in the form of rays or columns of light, they are described as being parallel to the dipping needle.*

The AURORA AUSTRALIS has not been so frequently witnessed. Captain Cook, in his second voyage to the South Pole, says: "(February 17th, 1773,) We observed a beautiful phenomenon in the heavens, consisting of long columns of clear white light, shooting up from the heavens to the eastward, almost to the zenith, and gradually spreading over the whole southern part of the sky. Though these columns were in most respects similar to the Aurora Borealis, yet they seemed to differ from them in being always of a whitish colour. The stars were sometimes hid by, and sometimes faintly to be seen through, the substance of these Auroræ Australes. The sky was generally clear when they appeared, and the air sharp and cold, the thermometer standing at the freezing point; the ship being in latitude 58° south." This phenomenon has been more recently observed

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* On the 24th October, 1847, a very splendid aurora was seen over the greater part of England. It had the rich red and green colours of the Arctic aurora, and its brilliancy was so great that it dimmed the planets and rendered the stars of the third magnitude invisible. It occupied the whole of the northern zone from horizon to zenith.

and described by Sir James Clark Ross. He witnessed it for the first time on the 28th February, 1841, in lat. 69° S. and long. 167° E. It was seen in the magnetic direction bearing west. He describes it as consisting of two segments of a broken arch, at an altitude of 15°; from which bright coruscations shot upwards, to the altitude of about 60°. The upper points of these rays were more beautifully attenuated than those of the Aurora Borealis. They were without colour, and the vertical beams had much lateral motion, and frequently disappeared and reappeared in a few seconds of time. In lat. 60° it was again seen, of a yellow colour, forming an arch 20° high, and at times exhibiting vivid flashes of a bright pink colour. On several other occasions it was seen in the form of bright flashes of all the prismatic colours, green and red being the most frequent and conspicuous. Hence this phenomenon is precisely the same, and is probably as frequent in the antarctic, as in the arctic regions.

12. OF THE RAINBOW. This beautiful phenomenon is dependent on the decomposition of light by the small spheres or globules of rain in the act of falling through the air. In order that it should be seen, it is necessary, for reasons to be presently explained, that the sun should not have a greater elevation than 54° above the horizon; hence rainbows never occur at mid-day: and, secondly, that the spectator should face the shower of rain, and be placed with his back to the sun. There are commonly two bows, but the inner bow is always the brightest; and each may be easily known from the other by the fact, that the red colour forms the outer margin of the inner, while the violet colour forms the outer margin of the outer bow. The inversion of the colours is owing to the light entering the series of drops which form the two bows at entirely different points. The interior bow is formed by the rays of light falling on the *upper parts* of the drops of rain; for a ray of light entering the upper part of a drop of rain will, by refraction, be thrown upon the inner part of the spherical surface of that drop, whence it will be reflected to the lower part of the drop, where, undergoing a second refraction, it will be bent towards the eye of the spectator; hence the rays which fall upon the interior bow come to the eye after two refractions and one reflection, and the colours of this bow from the *upper part* are *red*, *orange*, *yellow*, *green*, *blue*, *indigo*, and *violet*. The exterior bow is formed by the rays of light falling on the *lower parts* of the drops

of rain; these rays, like the former, undergo two refractions, *viz.* one when they enter the drops, and another when they emerge from them: but they suffer two or more reflections in the interior surface of the drops; hence the colours of these rays are not so strong and well defined as those in the interior bow, and appear in an inverted order, *viz.* from the *inner part* they are *red, orange, yellow, green, blue, indigo,* and *violet.* To illustrate this by experiment, suspend a glass globe filled with water in the sunshine, turn your back to the sun, and view the globe at such a distance that the part of it the farthest from the sun may appear of a full red colour, then will the rays which come from the globe to the eye make an angle of 42 degrees with the sun's direct rays; and if the eye remain in the same position, and another person lower the glass globe gradually, the orange, yellow, green, and other colours, will appear in succession, as in the interior bow. Again, if the glass globe be elevated, so that the side nearest to the sun may appear red, the rays which come from the globe to the eye will make an angle of about 50 degrees: then, if another person gradually raise the glass globe, while the spectator remains in the same position, the rays will successively change from red to orange, green, yellow, &c., as in the exterior bow. These observations being understood, let *d n e* (*Plate* IV. *Fig.* 1.) represent a drop of rain belonging to the interior bow, s*d* a ray of light falling on the *upper part* of the drop at *d;* instead of the ray continuing its direction towards F, it will be refracted or bent towards *n*, whence part of it (for some will pass through the drop) will be reflected to *e*, making the angle of incidence *dn*K equal to the angle of reflection *en*K; instead of continuing its direction from *e* towards *f*, it will, by emerging out of the water into the air, be again refracted to the eye at O. But, as this ray of light consists of a pencil* of rays, some of which are more refrangible† than others, the violet, which is the most refrangible, will proceed towards B, and the red, which is the least refrangible, will proceed towards O. Now, if the eye of the spectator be so placed that the ray of light falling upon it has been once reflected, and twice refracted, so that O*e* shall make, with the solar ray, S*d*, an angle S*m*O of 42° 2′[*], he will see the red ray in the direction O*em*; and if the eye be raised to B, so that B*e* shall make, with the solar ray S*d*, an angle BFS of 40° 17′ the violet ray will be seen in the direction B*e*F; the red ray will appear the highest, the violet the lowest, and the rest in order according to their different refrangibility, as in the interior bow (*Plate* IV. *Fig.* 2.); for the drop of water descends from F to *e*. What has been observed of one drop of water will be true of an infinite number of drops; hence the interior bow is composed of a circular arc, whose breadth F*e*, is proportional to the difference between the least and most refrangible rays.

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* A pencil of rays is a portion of light of a conical form *diverging* or proceeding from a point; or tending to a point, in which case the rays are said to *converge.*

† Refrangibility of the rays of light is their tendency to deviate from a rectilinear course. Those rays which deviate the most from a rectilinear course, in passing out of one medium into another, are said to be the most refrangible; and those which deviate the least, are the least refrangible. Sir Isaac Newton, by experiment, found the red rays to be the least and the violet rays the most refrangible.

To explain the exterior bow, Let C*tnd* (*Plate* IV. *Fig.* 1.) represent a drop of rain, S*d* a ray of light falling upon the under part of it at *d;* instead of this ray continuing its direction towards *m*, it will be refracted to *n*, whence part of it will pass through the drop, and the rest will be reflected to *t;* at *t* a part of it will again pass through the drop, and the remainder will be reflected to C; then in emerging from the water into the air, instead of continuing the direction C*z*, it will be refracted from C to the eye at O. But as this ray of light, like that in the interior bow, consists of a pencil of rays of different refrangibility, the red, which is the least refrangible, will proceed towards A; and the violet, which is the most refrangible, will proceed towards O. Now, if the eye of the spectator be so placed that the ray of light falling upon it has been twice reflected, and twice refracted, so that O*o* shall make with the solar ray S*o* an angle S*o*O of 54° 7′, he will see the violet ray in the direction OC*v;* and if the eye be raised to A, so that A*o* shall make with the solar ray So an angle SoA of 50° 57′, the red ray will be seen in the direction p A C r; the violet ray will appear the highest, and the red ray the lowest, and the rest in order according to their different refrangibility, as in the exterior bow (*Plate* IV. *Fig.* 2.) for the drop of water descends from H to *d*. The same observations apply to an infinite number of drops, as in the interior bow.

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[*] The sine of incidence and refraction of the least refrangible ray, out of water into air, is as 3 to 4, or as 81 to 108; and the most refrangible, as 81 to 109. (Emerson's Optics, p. 92.) The same author, at page 237. prob. xxvi. of his Optics, by the method of fluxions or increments, and using the numbers above, finds that the angle which the emergent ray makes with the incident ray in the interior bow, is 42° 2′ for the red, and 40° 17′ for the violet; and for the exterior bow, these angles are 50° 57′, and 54° 7′. The investigations are here omitted, because they cannot be rendered intelligible to any persons but mathematicians.

Hence, if the sun were a point, the breadth of the exterior bow would be (54° 7′ − 50° 57′ =) 3° 10′, that of the interior bow (42° 2′ − 40° 17′ =) 1° 45′, and the distance between them (50° 57′ − 42° 2′ =) 8° 55′; but, as the mean diameter of the sun is about 32′ 2″, the breadths of the bows must be increased by this quantity, and their distances diminished; the breadth of the exterior bow will then be 3° 42′, that of the interior bow 2° 17′, and their distance 8° 23′. The greater semi-diameter of the interior bow will be (42° 2′ + 16′, the sun's semi-diameter =) 42° 18′, and the least semi-diameter of the exterior bow (50° 57′ − 16′ the sun's semi-diameter =) 50° 41′.

All rainbows are arcs of equal circles, and consequently are equally large, though we do not always see an equal quantity of them; for the eye of a spectator is the vertex of a cone, and its circular base is the rainbow, the semi-diameter of which (for the interior bow) is the fixed quantity 42° 18′, equal to an angle FOP; and as SF will in all situations be parallel to OP, and the angle SFO, equal to FOP, must be always equal to 42° 18′, it is evident that as S rises, F and P will sink; and when SF makes an angle of 42° 18′ with the horizon, OF will coincide with OQ, and the interior bow will vanish; hence, the interior bow cannot be seen if the sun's altitude exceed 42° 18′: again, as the point P rises, the point S will sink, and when OP coincides with OQ, SF will be parallel to the horizon, (*viz.* the sun will be rising or setting,) and the whole semi-diameter of the rainbow will appear, which is the greatest part of it that ever can be seen on level ground; hence half a circle is the most that can be seen in such a situation; but if the observer be on the top of a high mountain, such as the Andes, with his back to the sun, and if it rains in a valley below him, a complete circle of colours may be seen. The above reasoning is equally applicable to the outer bow; hence, as the sun rises, the bows sink, and when his altitude exceeds 42° 18′ the interior bow cannot be seen, and, when it exceeds 54° 7′ + 16′ =) 54° 23′, the exterior bow becomes invisible.*

CHAPTER X.

Of Climate and Temperature. Hottest and coldest Months and Days. Extremes of Cold and Heat in the same Latitude. Effect of Altitude and Latitude on Temperature. Line of perpetual Snow. Influence of Soil — Vegetation — Proportion of Land and Water — Influence of Clouds, Rain, and Winds on Climate. Subterranean Heat.

1. MEAN TEMPERATURE OF PLACES. —It is well known that climate does not depend on temperature only, although this is one most important element, embracing as it does the consideration of the temperature of the earth and sea at various depths, as well as of the atmosphere at various elevations above the sea-level. Climate is also subject to important variations, according to the quantity of aqueous vapour contained in the air, and the prevalence of particular winds. It is probably influenced by light, electricity, and magnetism, although in a less appreciable degree.

It is a common error to suppose that the temperature of a climate depends on the latitude, and that a country is warm in proportion as it is near to the equator, or cold as it is near to the poles; but in truth it requires only a slight examination of the subject to observe, that there are many circumstances which have an indirect influence in increasing or diminishing the effect of solar heat. So far as the agency of the sun is concerned, the temperature of a climate certainly depends, first, on the directness with which the rays meet the surface of the earth; and, secondly, on the length of the period during which these rays are transmitted, *i. e.* the length of time which the sun remains above the horizon. There are, however, numerous circumstances of a local nature which modify the effect of solar heat; and among these may be enumerated the elevation of land in the form of mountains, the vicinity of the sea, the nature of the soil, its degree of cultivation, and other accidental conditions. It was long since observed by Humboldt, that *altitude* would compensate for *latitude;* and thus, as it is well known, every variety of climate may be met with in tropical regions by ascending lofty mountains. There is one point in which all meteorologists agree, namely, that for places in the same latitude the *mean temperature* is always, *cæteris paribus*, higher on coasts and on islands, than it is in the midst of large continents.* The thermometer has also a much greater

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* As the sun, the eye of the spectator, and the centre of the bow, are always in a right line, so it follows that a complete semicircle can be seen only at sunset or sunrise: and at other times only so much of the bow will be seen, as is equal to the number of degrees which the sun is above the horizon deducted from 42° for the inner, and 54° for the outer, bow. As no circle can have more than one centre, and as the eye of the spectator represents the centre of the coloured circle, so it follows that no two individuals, however close to each other, can see the same rainbow. The sheet of spherules of rain, therefore, presents to the eye of each spectator a separate bow.

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* As the terms *mean temperature* are frequently employed, it is necessary to state that they imply the average result of a series of temperatures, observed during a certain number of hours throughout the day, forming the *diurnal mean.* By adding together the diurnal means, and dividing by the number of days in a month, we obtain a *monthly mean.* By adding together the monthly means, and again dividing, we obtain the *yearly mean. The mean temperature of a place is the sum of the annual means observed for a series of years.* This is always implied when it is not otherwise stated; and it is obvious that in such an extended series of observations minor variations are lost. A country may have a summer as well as a winter mean temperature, — the thermometrical observations being then confined to each season. It has been ascertained by numerous observations, that in these latitudes the maximum temperature of the day occurs about 2 o'clock P.M., and the minimum temperature about half an hour before sunrise. According to Pouillet, the mean temperature of the month of October for a place, nearly represents the annual mean.

One year may differ much from another in respect to its temperature, but there is no reason to believe that any climate is becoming progressively colder or hotter. On the contrary, these irregularities appear to be due to oscillations of temperature, or to changes which balance themselves in a long series of years. Many years are required to give a true annual mean. As a result of observations made during a period of twenty-one years in Paris, from 1806 to 1826, the mean temperature was found to be 51°·4; the lowest mean was in 1816, when it was 48°·9; and the highest in 1806 and 1822, in each of which years it was 53°·7, making a difference of only 4°·8 in that long period. If this difference be divided by the number of years, it will give an average annual error of 0°·23, rather less than a quarter of a degree on Fahrenheit's scale; and it is clear that observations carried on for a century would reduce this error to a very small amount, although it would then be only an average. The thermometer in its present perfect state, has scarcely been known one range, *i. e.* it rises higher and falls lower, in the latter than in the former case. Thus, to take the same parallel of latitude in North America, 57° N., it has been found that, while the mean temperature on the western coast is 45°·2, it is no more than 30° 2 in the interior of the continent. Then, again, the difference of range is such, that in the interior the summer is 10° warmer, and the winter no less than 38° colder than on the coast.

In countries near the equator, and on the same level, these great differences are not observed; and the mean temperatures of places, in the same parallel of latitude and at the same level, more nearly correspond. In passing beyond the tropics this conformity is lost, and hence has arisen the necessity for indicating the equality of temperature in places, by what are called *isothermal*[*] zones, or bands; *i. e.* comprising within two isothermal lines, without reference to latitude, all those places which have the same, or nearly the same, mean annual temperature. These lines of equal heat are not parallel to the equator, but are more or less convex or concave with respect to it. This plan of using isothermal lines was first proposed by Humboldt, and it has been extensively adopted in respect to a large number of places in the northern hemisphere, in which only accurate observations have been hitherto kept. Then, again, it happens that places, which are situated in the same isothermal zones, have very different mean summer and winter temperatures; the thermometer may have a large range in the one case, and a small range in the other. This has given rise to other subdivisions: those places which have the same mean summer temperature are called *isotheral*[†]; and those which have

hundred years; the proper way of employing it, to determine these important questions connected with temperature, has not been understood for half that period; hence it is unreasonable to look for great precision in the results. Had the thermometer been employed, as it is now, for a thousand years, how many interesting questions connected with climate and temperature, it would have enabled us to solve! Changes in climate might have been accurately determined, and laws laid down with respect to them: the question whether the earth has lost caloric in the lapse of ages, *i. e.* whether it be a mass cooling from a high temperature, might also have been placed on a definitive basis. It remains therefore for us, as Kaemtz suggests, to collect materials in order to enable future generations to solve these interesting problems.

[*] *ισός*, equal; *ϑέρμη*, heat.

[†] *ισός*, equal; *ϑὲρος*, summer.

the same winter temperature, *isochimal.*[*] Thus Lisbon, Bologna, Bordeaux, Aix, and Venice, are isothermal, *i. e.* they have the same mean annual temperature, or nearly so, 57°. Rome, Nice, and Paramatta, near Sydney, in New South Wales, although in opposite hemispheres, are isothermal; and the mean annual temperature of these places (between 61° and 62°) corresponds with the mean *winter* temperature of Algiers. The mean annual temperature of Naples (about 63°), corresponds to the mean winter temperature of Madeira, and the mean summer temperature of England. Correct observation has brought out some remarkable facts with regard to these isothermal zones or bands. Thus there are many places in Europe which have a much higher mean annual temperature than other places in North America, although these are situated several degrees farther south. The summer of New Archangel, on the western coast of America, is much colder than that of Abo, in Finland, although the latter place is more than 4° further north; and the mean annual temperature of Yakutsk, which is situated in the same parallel of north latitude as the Faroe Isles, is no less than 26° lower than the mean winter temperature of these islands!

In comparing the annual with the monthly means of places situated in the temperate zones, we perceive that the temperature begins to rise about the middle of January, and gradually attains its maximum, although with a more rapid increase in April and May than at other periods, towards the latter end of July. It slowly decreases in August, rapidly in September and October, and attains its minimum point about the middle of January. According to Professor Kaemtz, the days for maximum, mean, and minimum temperature, during the year are,

Minimum temperature - -	14th January.
Mean temperature - - -	24th April, 21 October,
Maximum temperature - -	26th July.

These points have been determined from observations made in Lapland, on the Persian Gulf, and in various places in the Old and New World. From the researches of Arago, extending over a long series of years, the days of greatest cold have generally coincided with the second week in January; while the days of greatest heat have been irregularly distributed through the months of July and August. Thus, then, in determining the temperature of the seasons, we cannot follow the usual astronomical divisions. The winter months should be so arranged for temperature that the middle of January should correspond to the middle of the winter season, and this would therefore consist of December, January and February. The same rule should be observed in determining the summer temperature, the average day of the maximum temperature forming the middle of the season. It is to be regretted that tables of the temperature of places have often been constructed without reference to any fixed principle, so that it has been quite impossible to compare them. Some have followed the astronomical seasons, while others have selected particular months for comparison. The mean summer temperature for England is 62°, and the mean winter temperature about 37°, thus giving an average range of 25°; but it is well known that the thermometer frequently rises very much higher and falls much lower; yet these variations, in a long course of years, compensate each other, and give a degree of constancy to climate, for the existence of which we should hardly, from personal experience, be prepared.

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[*] ισός, equal; χεῖμα, winter.

Most observers agree that the annual mean temperature of London is about 50°·4. In the severe winter of 1788, when the Thames was frozen over, the mean temperature was 50°·6; in 1796, in which there was a more severe winter than had ever been observed before, the mean was 50°·1; in 1813–4, when the Thames, and other large rivers of England, were completely frozen, the mean of the two years was 49° (Whewell); therefore about a degree below the standard. In the year 1808, the summer was remarkably hot, and the temperature in London was as high as 93°·5; yet, according to Whewell, the mean heat of the year was only 50°·5, very nearly the standard temperature. This compensation, however, does not always take place so closely as this statement would lead us to believe. The winter of 1837-8 was remarkable for the severity of the cold. On the 20th January, 1838, at sunrise, the thermometer stood in the immediate neighbourhood of London at 4° below zero Fahr., or about 41° below the mean winter temperature. This degree of cold, so unusual for London, lasted some hours. In calculating the mean temperature of that year, from the monthly tables of maxima and minima, collected by Dr. Armstrong, the *writer found it* to be 47°·35, — a difference of more than 3° below the mean; but it was remarked, that in this year, the mean temperature of every month, with the exception of that of June, was below the annual average of many years. It has been already stated that the mean temperature of October represents, approximately, the mean temperature of the year. In 1838 the October mean was 48°·5, differing, therefore, only by 2° from the annual mean.

The observations made in Paris during twenty years show that we must not expect the heat and cold of every year, so to compensate each other as to vary only by a fraction from the mean temperature. The difference, however, was so small, as to make less than 5° between the highest and lowest annual mean; and the low mean of 1838 for London would probably vanish, if the means for the years before and since were taken together. The winter of 1838 was unusually severe over the greater part of Europe.

2. EXTREMES OF COLD AND HEAT.—It is not so much, however, to the mean annual, as to the mean winter and summer temperatures, to which we must look for the great influence of climate on plants and animals. Thus certain plants are not found to flourish where the mean annual heat is above or below a certain point. *

Every zone has thus its peculiar plants, the flourishing of which depends more on the length and heat of the summer, and the length and cold of the winter, than on the mean annual temperature or the latitude of the place. This constitutes a most interesting branch of science, known under the name of Botanical geography. Thus the mean annual temperature of New Archangel, on the western coast of America, derived from the summer and winter means, is 45°·2; that of Moscow, calculated in the same way, is 38°·5.

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* The coffee-tree, cotton-tree, the indigo plant, sugar-cane, date, and vine, flourish only within certain defined limits of temperature. Indian corn does not grow to perfection except in a climate where the temperature, during at least one summer month, does not fall below 70°. Berghaus attributes the variety in the distribution of plants to three conditions: 1st, the mean temperature of the year, 2nd, the extreme temperature both as regards heat and cold; and 3d, the distribution of temperature among the different months of the year. The last especially, as it refers to the heat and duration of the *summer* months, is the most important; for many plants, protected from the action of the atmosphere by a covering of snow, are enabled to brave the most rigorous winters, and to pass through all the phases of flowering and fructification, *provided the summer* be hot enough and of sufficient duration.

Humboldt has made it as low as 35°, although Moscow is in latitude 2° south of New Archangel. It might be supposed that a plant like wheat, which requires solar heat for its ripening, would be more likely to flourish at New Archangel than at Moscow, if we judged by mean annual temperature; but it would appear that, while grain readily ripens at Moscow, it cannot be grown at New Archangel. The cause of this apparent anomaly is, that the ripening of grain depends more on the mean *summer* than on the mean *annual* temperature: this at Moscow is 64°, while at New Archangel it is only 56°. In the former place the extremes of heat and cold are greater; extreme cold has very little influence on grain, for it lies dormant during the winter, but a high summer temperature is absolutely necessary for its ripening. In New Archangel the heat and cold are more uniformly diffused than at Moscow, so that the winter is warmer than many places farther south, and the summer is much colder than other places farther north. Perhaps a still more remarkable instance exists in the case of Yakutsk, the capital of Eastern Siberia. The mean temperature of this place, owing to the severe cold of winter, is below the freezing point of water; — the mean winter temperature is nearly 40° below the zero of Fahrenheit. The summer, although short, is warm enough to ripen wheat, barley, potatoes and other vegetables; and Yakutsk lies 5° farther north than New Archangel. In judging, therefore, of the influence of climate on vegetation, we must look to something more than mean temperature. Two places may have the same, or nearly the same, mean temperature, and yet a very different yearly range: the *degree* of this range, as well as the *rapidity* with which the changes producing it take place, must have a decided influence upon health. Such differences are seen when we compare places situated on coasts and islands, with others which are in the interior of continents. This will be evident on comparing the temperature of Berlin, Dublin, Edinburgh, and London:—

	Mean temp.	*Winter temp.*	*Summer temp.*	*Range.*
Berlin - - -	47°	31°	62°	31°
Dublin - -	49	40	60	20
Edinburgh - -	47	39	58	19
London - -	50	37	62	25.

It will be perceived by this table that there is a difference of 11° in the range between Berlin and Dublin, and of 12°

between that of Berlin and Edinburgh; while there is a difference of only 6° in the ranges of Berlin and London. The winter temperature of Berlin is lower than that of the other three places, while the summer is higher, with the exception of that of London, which is equal or nearly so. The decimal differences are here omitted.

When we compare places situated in the same parallel of latitude on islands and continents, the difference is often very remarkable. Thus in taking the Faroe islands and Yakutsk, which are on the same parallel of north latitude, 62°, the following results are obtained: —

	Mean temp.	*Winter temp.*	*Summer temp.*	*Range.*
Faroe islands - -	46°	40°	53°	13°
Yakutsk - -	14	−39	63	102

The difference in range is nearly 90° at these two places, a difference which might be considered almost incompatible with health and life, were it not for the extraordinary power which man possesses of adapting himself to climate. It is to be observed, that where there is so great a range it is quite impossible to calculate the mean annual temperature from the sum of the mean summer and winter temperatures. When the annual range is small, such a calculation may be made without producing any great error, because this is a proof of the heat being more equally diffused throughout the year. These remarks, then, will show that the *average range* of the thermometer is of more importance, in reference to climate, than the determination of the mean temperature of a place.

Another point connected with the temperature of climate is that which appertains to the extremes of heat and cold observed in particular localities. Thus observations have been made by travellers of the maxima and minima of temperature noticed in different parts of the globe; and these facts have been collected without reference to the mean of the year, or of the seasons. In the oasis of Moorzouk, in the great African desert, the thermometer has been observed to stand, in a sheltered spot, at 128°; in Upper Egypt, under a tent, at 138°; in the valley of the Indus, during the Affghan expedition, at from 138° to 140°. At Calpee, in the East Indies, the thermometer on one occasion was observed by Mr. Davidson to stand at 150° in the open air, half an hour after sunset. In the engine-rooms of our steam-ships employed on the West India station, the thermometer has been seen as high as 154°.[*] The temperature occasionally rises very high in places situated within the temperate zones. In Paris, in the summer of 1793, the thermometer rose to 101°, which is nearly as high as it has been observed at Madras and Cairo. In Cumberland, U. S., lat. 38°, it rose in 1838 to 108°. In the summer of 1829 the writer observed the thermometer to stand, in the shade, at Milan at 105°.

When favourably exposed to direct solar influence during the summer, the thermometer has been known to rise in this latitude to 115° and 120°. The quantity of heat which reaches the ground during the summer season is enormous, even on a few square inches of soil; and were this not absorbed or carried off by evaporation, the surface would soon be reduced to a sterile waste. In some experiments on the power of the solar rays, performed during the summer of 1844, at the period coinciding with the maximum annual temperature, the writer found that the quantity of heat falling in a second upon less than *six square inches* of surface, measured by a lens, was sufficient to ignite gunpowder in a second. This is equal to a temperature of 545°. The extraordinary capacity for heat which water possesses, counteracts, under the common phenomena of evaporation, these powerfully heating effects of the solar rays.

When a thermometer is enclosed in a box of smoked or blackened cork, and exposed directly to the rays of the sun, without being influenced by reflection or radiation from other sources, it has been observed to rise to a very high temperature, far above that of boiling water. Professor Robinson, of Edinburgh, in one instance observed that a thermometer, thus protected, rose to 237° ; and Saussure made a similar observation at Geneva, in which the thermometer attained a temperature of 221°. Here it will be seen that there was a mere accumulation of the direct rays of heat from the sun, and no concentration by the aid of a mirror or lens.

Let us now pass to the consideration of the extraordinary degrees of cold, natural and artificial, recorded by various observers. It is to be remembered, that the zero of Fahrenheit's thermometer is 32° below the freezing point of water: degrees below this, have consequently the — sign placed before them.

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[*] As an instance of the excessive heat in Barbary, Mr. Davidson states, that he on one occasion found the water of a tank, exposed to the sun, to have a *temperature of* no less than 112°.

	Below zero, F.
Melville Island, m. t. zero, F.	
Nain, Labrador, winter temperature	1·2
North America (open continent)	4
London, January, 1838	4
Alten, Norway, winter, 1843	16·6
Storvansfjeld mountain, 1843	31
Tobolsk, winter temperature	31
Steppes of Southern Russia, winter temperature	35
St. Petersburg, minimum temperature	35
Lake Baikal, winter temperature	40
Yakutsk, Siberia, winter temperature	40
Rae's Arctic Expedition (Jan. 8. 1847), lat. 66° 32′ N. long. 62° 30′ W.	47
Hudson's Bay, min. temperature	50
Melville Island, 1820, (Parry)	55
Great Bear Lake, 1827, (Franklin)	58
Supposed temperature of space, the resisting medium (Fourier)	58
Ross's Northern Expedition	60
Nijne Kolymsk, Siberia, winter temperature, 1821	65
Yakutsk, Siberia, minimum temperature (Ermann)	72

Kaemtz states that Captain Back, at Fort Reliance, observed a temperature of —56°·7 C., which would be equivalent to —70°·3 Fahrenheit; but this appears to be one of those mistakes depending on the confusion of thermometers, as nothing like this temperature has been observed by other arctic travellers. The greatest degree of natural cold yet noticed on the surface of our globe, was that recorded by Ermann, at Yakutsk in Siberia, in January, 1829. The thermometer fell 72° below zero F., or 104° below the freezing point of water. For two months in every year this town, which is the capital of Eastern Siberia, has a mean temperature of —40°; in other words, during that period mercury is solid. The difference between the highest degree of observed natural heat and the lowest degree of observed natural cold amounts to 220°,—an extraordinary range of the thermometer for human beings to bear, consistently with the maintenance of health and life.

The actual zero of cold, as well as the maximum of heat, is unknown. Among the low degrees of artificial cold may be mentioned:

	Below zero.
Carbonic acid gas	70°
Solid carbonic acid cools by evaporation to	148
Lowest artificial cold marked by alcohol	166*

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* This intense degree of cold, *i. e.* 198° *below* the freezing point of water, was produced by Mr. Faraday in mixing solid or crystallised

3. EFFECT OF ALTITUDE ON CLIMATE.—It is well known that as we ascend in the atmosphere, the thermometer, *cæteris paribus*, falls; and that, at a certain elevation, varying according to the latitude, and slightly fluctuating in the temperate zones according to the seasons, the thermometer is at or near the freezing point; in other words, there is eternal snow. The line of perpetual snow in the equatorial regions of South America is at the height of 18,300 feet; in the Alps it is at 8900, and in Norway (lat. 71°) at 2400 feet. In the Alps it is 700 feet lower on the northern than on the southern side: in the Himalaya mountains this condition is reversed; it is 3000 feet lower on the side towards Tartary than on that towards India.* In no part of Great Britain do the mountains reach the line of perpetual snow, which would be in this latitude at an elevation of about 4500 feet.†

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carbonic acid gas with ether in vacuo. He thinks the actual degree of cold should be taken at 204° below freezing. Lower than this we are not likely to go, as at this temperature, the alcohol in the thermometer became oily and thick, so that it ceased to mark temperatures with any certainty. Taking the zero of Fahrenheit as a mean point, the measurement of degrees of heat has been carried much farther above this, than the measurement of degrees of cold has been carried below it. Fahrenheit believed his zero to be the lowest producible degree of cold; but an inhabited town (Yakutsk) is now known, the winter temperature of which has sunk to 70° below this point; and by an artificial process of recent discovery, the degrees of cold may be carried to 187° below it. These facts show that, in constructing thermometers, it is absurd to look for the positive zero; but, in arbitrarily fixing it, we should take some well-marked point above which the greater number of natural and artificial temperatures would fall. This point appears to be that which corresponds to the freezing of mercury.

* The snow line on the north of the Himalaya mountains is at the height of 16,625 feet; and on the south side, 12,980 feet. On the north side there is varied cultivation, with good crops, at the height of 13,000 feet: and Captain Gerard found vegetation in full activity at an elevation of 16,800 feet in lat. 32°; while, on the southern side, it hardly reaches 10,000 feet. The birch grows at 14,000 feet on the north side, and the oak at 11,500 feet on the southern side. (Berghaus.)

† The influence which altitude exerts on the growth of plants and the distribution of animals, is entirely dependent on temperature. Thus the birch grows on the Caucasian mountains at a height of 6394 feet: in Lapland it forms the upper limits of trees at 1918 feet; in the Himalayas it grows at an elevation of 14,000 feet. In the ascent of the Alps the walnut and chesnut are succeeded by the oak, the beech, and the birch tree. At about 2600 feet the oak ceases to grow; the beech con-

From numerous observations made in England and on the continent, it has been calculated that in these latitudes the thermometer falls about one degree for an elevation of 300 feet,—some make it 319, others 334 feet. In the celebrated ascent of Gay Lussac, in which he attained an altitude, over Paris, of 23,000 feet, the thermometer fell 72°. At the maximum elevation he observed it to stand at about 16°. This gives an average of one degree for 319 feet elevation; but calculations of this kind can only be regarded as approximations to the truth. Latitude makes a difference in this respect; thus, while the thermometer has been observed to fall one degree for 270 feet elevation in England, it falls only to the same amount for 352 feet elevation in Switzerland, according to observations made on the Great St. Bernard. It is also possible that there may be a difference in the rate of increase at high, compared with that observed at low elevations; and that the season of the year at which the observations are made, with other local circumstances, may affect the results.

4. EFFECT OF SOIL AND VEGETATION.—The nature of the soil, as well as the degree to which it is covered by vegetation, will affect the temperature of a climate. A country overrun with forests is kept comparatively cool, partly by the calorific rays being prevented from reaching the earth, and partly by the abundant evaporation which takes place from living vegetables. On the other hand, where vegetation is wanting, as in the sandy deserts of Africa, Arabia, and Persia, the ground is parched and dry, and the atmosphere attains a very high temperature.

5. RELATIVE PROPORTION OF LAND AND WATER.—It has already been stated that the climates of countries near the sea are subject to less rapid changes, and are of more equable temperature, than those which are inland. The neighbourhood of the sea, therefore, is generally observed to give mildness

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tinues until about 3200 feet; beyond this are the pine, the larch, and the common fir; and these cease altogether at 5900 feet. In the high land of Mexico the upper limit of trees is the western pine, which grows at an elevation of 12,789 feet.

A species of monkey (*Semnopithecus entellus*) is found on the Himalayas, at the height of above 13,000 feet. In Africa another species (*Macacus montanus*) is found in the Abyssinian highlands at a height of 8000 feet; and in the new world, the *Mycetus rufinanus* is met with on the eastern declivity of the Andes, at an elevation of above 11,000 feet. (Berghaus.)

and uniformity to the temperature of a climate. The difference appears to depend on the different degrees of radiating and absorbing power possessed by land and water in respect to the solar rays.

Mr. Hutchison observes, that the mean annual range of temperature of the surface of the Atlantic is only about 9°, while for inland continental countries in the same latitudes it is 100°. It is not often, however, that we meet with so great a range as this. According to the same authority, the extreme atmospheric temperatures of day and night over the ocean in the equatorial regions never exceed 3° or 4°, while upon the land the difference is 9° or 10°. Between the 25th and 50th parallels of latitude, the extremes in the diurnal range of temperature at sea, are only from 4° to 5°. Between the same parallels on land, as at Paris, it amounts from 25° to 30°! These differences are due, not merely to the greater capacity for caloric possessed by water, which, together with the loss of heat by evaporation, tends to the cooling of the air during the day, but also to the sinking down of the cold and the rising of the warmer strata during the night. It follows from this, that during the summer and during the day, the land is much hotter than the sea; while during the winter and at night, the sea is generally much warmer than the land.* The great effect of evaporation consists in not only lowering mean temperature, but in diminishing the effect of any extreme fluctuations from it. It has been observed, that if the entire surface of the earth were divided into 2000 equal parts, the land would occupy about 548 of these, and the rest would be water; a proportion of nearly two and two thirds water to one of land. This land, it is well known, is very unequally distributed. Assuming that the northern hemisphere is divided into 1000 equal parts, the land occupies 419 of these parts, or nearly one half of the whole. If the southern hemisphere were supposed to be equally divided, the land would form only 120 parts, or a little more than one eighth of the whole. The heating power of the sun on land being much greater than on water, the northern hemisphere has a higher mean temperature than the southern, and the hottest band of the earth lies more to the north than the south of the line; and for a like reason the variations of temperature are much greater in the northern than in the southern hemisphere. The greatest preponderance of land is in the northern temperate zone; and here, perhaps, the range of the thermometer is far greater than in any other part of the globe.

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* See his Observations in the Athenæum, 1837, p. 564.

The mean temperature of the air at the equator on the surface of the sea is about 81°,—the sea-water being about 83°. The mean temperature of the air on the sea between the 45th and 50th parallels is about 49° ; and it rarely falls below this temperature, even in mid-winter. The mean temperature of the air in the polar sea is about 18°, which nearly corresponds to the mean winter temperature of the air in the Gulf of Bothnia.

6. INFLUENCE OF ELECTRICITY.—The electrical state of the air must also exercise a modifying influence on the temperature of climates, although no accurate observations have been made on this point. When we know from the use of the thermo-electric apparatus that changes of temperature inappreciable to our feelings, and to the most delicate thermometer, are immediately indicated by the production of currents of electricity, it is only a fair inference that electricity must react upon heat, and produce changes in climate for which we are otherwise unable to account.

7. INFLUENCE OF CLOUDS, RAIN, AND WINDS.—The temperature of climates is liable to be materially affected by the prevalence of clouds, rain, or of particular winds.

8. CLOUDS.—The effect of *clouds* is easily understood; they tend to increase the mean temperature of a locality during *winter*, because they intercept and throw back the heat which at this season is so abundantly radiated from the earth's surface. As at this period of the year the earth radiates or throws off more heat than it receives from the sun, the prevalence of clouds has a remarkable influence on the temperature. This influence has been fully understood since the interesting discovery made by Dr. Wells relative to the deposition of dew. On clear and bright nights, especially at those seasons of the year when there is the greatest difference between the temperature of the day and night,—*i. e.* in spring and autumn, the earth becomes cooled by radiation sometimes as much as 20° below the temperature of the air above it, whereby the whole of the aqueous vapour contained in that stratum of air becomes deposited under the form of dew,—a clear proof

of the great cooling which takes place on the earth's surface. When, however, the night is cloudy no dew is deposited, the heat radiated from the earth is prevented by the clouds from passing into space and tends to raise the temperature of the air between the clouds and the earth: for this reason, cloudy nights in winter are warm nights. On the other hand, the effect of clouds in *summer*, or during the day, is to lower the temperature; because at these times the earth receives more heat from the sun than it radiates, and the access of this heat to the earth is thereby cut off: hence it is not difficult to appreciate the great influence which clouds have on the temperature of climates. Cloudless districts must be parched with a burning heat in summer, and, *cæteris paribus*, be intensely cold in winter.

9. RAIN tends to lower the mean temperature of a locality, and it does this partly by its falling from the higher regions of the air, which, as we know, are much colder than the lower; and partly by its carrying off heat by evaporation, tending to a great cooling of the earth's surface, and of the strata of air immediately in contact with it. This cooling effect is most manifest during the summer season, at which time rain falls at a low temperature from a great elevation, and is rapidly evaporated. The line of perpetual congelation in the atmosphere in this latitude being at an elevation of about 5000 feet from the earth's surface, it is probable that the hail which frequently falls in summer is formed in the atmosphere at levels higher than this. In winter, if much rain falls, it has not the same cooling effect; because evaporation takes place more slowly, and the temperature of the falling rain is not commonly lower than that of the earth and of the lower strata of air. In India the effect of the intense solar heat is moderated by the abundant rains accompanying the monsoons. Hence, it follows that wet climates have, *cæteris paribus*, a mean temperature lower than that of dry climates: and this conclusion is borne out by observations made in various parts of the world. The cooling effect of frequent rains may, however, be counteracted by the circumstance of the locality being littoral or insular. The differences above stated are chiefly met with in the interior of continental and tropical countries.

10. WINDS.—The most complete account of the effect of winds on the temperatures of climates is that given by

Kaemtz.* The observations have been chiefly confined to the northern temperate zone; they were made with regularity at London, Hamburgh, Halle, Pesth, Moscow, and Stockholm. The following table will show, what common experience testifies, that the coldest wind blows from a direction between north and east, while the hottest comes from the opposite quarter, *i. e.* south and west.

	Coldest Wind.	Warmest Wind.	Dif. of Temp.
London	N.	S. 12° W.	6°
Hamburgh	N. 30° E.	S. 16° W.	5°
Halle	N. 30° E.	S. 17° W.	7·5
Pesth	N. 16° W.	S. 11° W.	6·5
Moscow	N. 19° E.	S. 42° W.	9
Stockholm	N. 2° E.	S. 26° W.	11·5

The decimals are omitted except in those cases where they would have affected the results by half a degree. In continental districts, it is found that the warmest wind, although blowing from the south-westerly quarter, is nearer to the west. The differences produced by the winds on temperature are more marked during the winter season, and their direction varies with the seasons. The *coldest* wind during winter blows from the north-east, and during summer from the north-west: while the *warmest* wind blows from the south-east in summer, and the south-west in winter.

In considering the causes upon which these differences depend, it is necessary to bear in mind, that winds always partake of the temperature of the countries over which they blow. This is the well-known explanation why the north wind is cold, and the south wind warm; but in fact, the coldest countries are situated to the east and west of north, and this gives a lower temperature to the winds blowing from these quarters. Other circumstances also influence the temperature of winds. Thus in winter the warm south-westerly wind is charged with vapour, which tends to check evaporation,—a main source of cold: this wind also brings clouds, which prevent radiation. The same conditions render the south-westerly a very *cold* wind in summer,—the clouds preventing the solar heat reaching the earth, and the humidity leading to excessive evaporation. The southerly wind blowing over the south continent favours radiation, and the winds blowing from the east at this time of the year favour evaporation, and cause the thermometer to fall. These winds have also an influence on diurnal temperature, which may be understood from their effect upon the seasons.

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* Cours de Météorologie.

11. TEMPERATURE OF THE EARTH.—The most careful researches tend to show that the *temperature* of the surface of our globe, including that of the air, earth, and sea, depends exclusively upon the quantity of heat transmitted to it from the sun. The heat thus received is again lost, partly by radiation into space, and partly by conduction downwards through the superficial strata. The chief loss undoubtedly takes place by radiation; and it is by the amount of this, that we learn the temperature of the medium (space) in which our globe is floating. The lowest natural temperature hitherto observed on the earth, was determined by Ermann at Yakutsk, the capital of Eastern Siberia. In January, 1829, the thermometer was observed by him to fall to 72° below the zero of Fahrenheit, or 104° below freezing.* Now, according to the laws which regulate the diffusion of heat, space must be at or below this temperature†; and were there not an annual compensation by the heat derived from the sun, the surface of the earth, notwithstanding the assumed existence of subterranean heat, would be speedily

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* The difference between the temperatures of the north and south polar regions, may be judged of from the fact that the greatest degree of cold experienced by Captain Sir J. C. Ross, in February, 1842, in lat. 70° S. was 17°; but the mean temperature of the month was 26°, and of the sea at the surface 29°. The latitude of Yakutsk is 61°·55 N.

† The following explanation may be offered respecting this theory. When a heated body, placed in a medium like the atmosphere, cools, this can only happen by the tendency to an equilibrium of temperature. If an iron ball heated to 500° were suspended in a room, the air of which was always at a temperature of 500°, the ball would not cool. If the ball at any time cooled, so that its surface had a temperature of 32°, it would follow, that the air or medium must be at, or below, this temperature, for if it were above it, the ball could not, according to the laws which regulate the equal diffusion of heat, be below it. A point on the earth's surface has been observed to fall to a temperature of 104° below freezing. This could only happen by the loss of heat radiated from the earth into space, or by the transmission of heat into the upper regions of the atmosphere by the lower strata of air in contact with the surface. In either case it follows, that the upper regions of the air, and the medium beyond them, must have a temperature at or below that to which the surface of the earth has been observed to cool. If the temperature were above this degree, we should have the impossible condition of a hot body becoming *cold* in a medium *warmer* than itself.

cooled to a temperature which would render it entirely uninhabitable. Some portion of the heat received by the earth from the sun is conducted downwards by the strata; but its progress is arrested within a very short distance of the surface; for the extent to which solar influence penetrates is exceedingly small. This is determined by burying thermometers in the earth, or fixing them at different depths in mines and other excavations. The experiments hitherto made lead to the following interesting results. Diurnal variations of temperature are not perceived beyond two or three feet. Variations depending on the months or seasons extend somewhat lower; and annual variations are entirely lost at a depth of from 60 to 100 feet, varying slightly in different localities.* The maximum depth at which changes in the thermometer are perceptible, amounts to only 1-400,000th part of the earth's diameter! Upon the alternate heating and cooling of this film, which does not exceed the nine-millionths of an inch in a globe of three feet in diameter, depend all the vicissitudes of temperature in climates, seasons, and cycles of years.

The extent to which the superficial strata become warmed by the sun must depend,—1st, upon the directness with which the rays fall,—hence it is greater in the tropics than in temperate regions, and greater in summer than in winter†;

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* How strongly is this contrasted with observations made on the waters of the *ocean*. Captain Ross found that, in a sea 9240 feet in depth, the influence of the sun's heat was perceptible for 450 fathoms, or 2700 feet!

† It is proper to state that the air is not heated by the solar rays which traverse it. It derives its heat solely by contact with the surface of the earth and bodies upon it, which absorb and retain heat. This may appear paradoxical, but it is a law that no transparent medium receives or retains heat. A glass lens which, by converging the solar rays, raises the temperature of gunpowder to 545° and explodes it, is itself perfectly cold. As another illustration of this fact, it may be mentioned that the writer has seen phosphorus ignited by a lens of *ice*, the rays of the summer's sun being converged by the ice to a focus. Phosphorus requires a temperature of 110° to cause it to burn. It has been found that an ice-lens caused gunpowder to explode, although this does not occur under a temperature of 545°. While it is thus producing a powerful heat by the convergence of the rays, the ice-lens itself remains at the temperature of freezing water, 32°. The melting of the surface of the lens during the experiment is owing entirely to the higher temperature of the surrounding air.

Ether is a highly inflammable liquid, and boils at the low temperature

2d, upon the conducting power of the strata, which is subject to great variation. It is, however, obvious that the *depth* to which this solar influence extends may be determined by the thermometer. If, below the surface of the earth, we can find a stratum in which, after a long series of careful observations made at all seasons of the year, and at all periods of the day and night, this instrument remains stationary, it is certain that we have reached a depth beyond which the power of the sun cannot extend. Such a stratum has been found, and it is called the stratum of INVARIABLE TEMPERATURE. Its position has been determined in some instances experimentally, in others theoretically.

The most accurate observations on the position of this invariable stratum in these latitudes, have been made at Paris. In July, 1783, a very delicate thermometer was placed by Lavoisier in an excavation beneath the Observatory of Paris, at a depth of ninety feet below the surface of the soil. This thermometer was so sensitive to changes of temperature, as to allow of the measurement of what would be equivalent to the one-hundredth part of a degree on Fahrenheit's scale. From the observations of Cassini, Bouvard, and others, extending over a period of *fifty years*, this thermometer has remained stationary at a point corresponding to 53° F., which is about a degree and a half above the mean temperature of the climate of Paris. On one occasion only, within the last seventeen years, it was observed to rise about a *quarter of a degree!* This was attributed to the effect of currents of air resulting from some excavations being made in the quarries adjoining the Observatory. Hence in Paris the position of an invariable stratum of temperature is fixed at from 80 to 100 feet below the surface. In no other place in the world has so extensive a

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of 96°. It is perfectly colourless and transparent. On throwing on it the solar rays by the focus of a glass lens, which caused gunpowder to explode in a second, the temperature of the ether was not raised, or in any way affected; the heating rays met in a focus in the centre of the liquid, and traversed it without heating it, but caused the ignition of German tinder immediately, when the rays were thrown through the ether upon this substance. Upon projecting some powdered charcoal (an opaque substance) into the ether, and throwing the rays on the particles of charcoal, the ether boiled.

These facts will explain how it is that the air is not heated by the solar rays, and why an intense degree of cold must always reign in the upper regions of the atmosphere.

series of observations been made: but from a few data, and from theoretical considerations, the stratum has been considered by Humboldt to exist throughout Europe, between the parallels of 48° and 52°, at a depth of from 55 to 60 feet. Professor Thomson makes its depth below the surface in England to be from 30 to 60 feet; and the experiments performed by Mr. Fox on the mines of Cornwall, render it probable that in that county, it is situated at from 60 to 75 feet.

One test which has been proposed for the invariable stratum, is, that its temperature should correspond to, or differ but little from, the mean temperature of the climate in which the observations are made. On this principle, Boussingault fixed its position in the tropics at one third of a metre, or rather more than a foot below the surface of the soil: but the recent experiments of Captain Newbold have shown, that this is an error; the *diurnal* variation at this depth amounting to as much as 2°·75 F. Captain Newbold found the thermometer to remain stationary, in a shady locality, at about four feet; *i. e.* at that depth the temperature corresponded to the mean of the atmosphere. In high latitudes, the position of the invariable stratum has not been accurately determined. The only correct observations yet made are those of Ermann and Baer, at Yakutsk, in Eastern Siberia. M. Baer ascertained that in this desolate region the ground is thawed, during the short summer, only to the depth of three feet; below this, at all periods of the year, there is a band of ice, or frozen soil, which has been perforated to the depth of 382 feet, but without entirely traversing it. The solar influence, therefore, scarcely extends, in the course of seasons, beyond three feet from the surface.

The invariable stratum must not be considered as a *line*, but rather as a *zone*, varying from 2 to 40 or 50 feet in thickness. Its course below the surface is probably that of a *curve*, its depth being affected by many local circumstances,—such as the nature of the strata, the situation of the place, whether it be on a plain, on a mountain, or in a valley,—in the midst of a vast continent, or in the vicinity of seas, lakes, and rivers. Whatever affects the mean temperature of a place must affect its position. The influence of the strata in altering the position of this zone, was observed by Captain Newbold in the tropics. He found a constant temperature to exist at four feet depth from the surface in *clayey* soils, but in order to obtain it in light *sandy* soils, it was necessary to go much deeper.

Professor Forbes has undertaken some interesting experiments on the conducting power of the strata in the neighbourhood of Edinburgh; but numerous observations are required in various latitudes before any satisfactory conclusions can be drawn on the subject: neither has the proportion between the quantity of solar heat radiated, and that conducted downwards by the earth, been correctly ascertained. One fact is certain, that when the earth is heated by the sun, that portion of heat which is not radiated or carried off by the evaporation of water from the soil—a condition which must cause the dissipation of an enormous quantity—is slowly transmitted to the interior; but when the quantity radiated exceeds the quantity received by the earth, as during the night or in the winter season, then a portion of that which has been conducted downwards must again return to the surface and be dissipated. Hence there will be a succession of waves of caloric descending or ascending, according to the temperature of the earth's surface. The quantity that descends must be small, and it will finally meet the ascending currents of caloric proceeding from the interior of the globe, whereby an equilibrium will be established.

12. SUBTERRANEAN HEAT.—If a thermometer be carried *below* this invariable stratum, it immediately begins to rise, and in a degree subject to some local exceptions, proportioned to the depth to which it is carried. It is obvious that this increase of temperature cannot be due to solar influence. —1. Because the existence of a zone of invariable temperature shows that the power of the sun must be limited to that portion of the earth's crust which is above it. 2. Because, if the interior heat of the mass of the earth were due to external or solar influence alone, the thermometer should fall just in proportion as we descend below the invariable stratum: but the reverse of this is the fact. Hence we are led to the conclusion, that in going below the invariable stratum, we are approaching some great source of heat, which must be situated within the interior of our globe.

It is not to be supposed, however, that the same increase is observed at equal depths in all places. As there are isothermal lines over the surface, so there are isogeothermal lines below it. Thus it was observed that among five of the principal mines of Cornwall, in three the air had a temperature of 64° at 500 feet below the surface; but in two of them it was necessary to go to the depth of about 700 feet, in order to obtain this temperature. An *isogeothermal*[*] line is, therefore, a curve of equal temperature below the invariable stratum, and when widely distant places are taken, considerable deviations are found. Thus, in the latitude of Paris, it was ascertained, by sinking the well of Grenelle, that in order to obtain a temperature of 72°, it was necessary to go to the depth of 1800 feet. In the Monkwearmouth mine, near Sunderland, the same temperature was obtained only at 1500 feet; in Joseph's well, at Cairo, at the depth of 210 feet: in the tropics this temperature exists still nearer the surface: in Siberia it is scarcely possible to assign the depth at which this temperature would be obtained, since at 400 feet the temperature of the strata begins to rise only above the freezing point. Making all due allowance for elevation and depression above the sea level, it is obvious that there must be great irregularity in these isogeothermal lines, or lines of equal terrestrial heat. Judging by the temperature of water, in some Artesian wells, there is a near approximation over great distances.

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[*] *ισός*, equal, *γὴ*, the earth, *ϑέρμη*, heat; a line of equal temperature in the earth.

The existence of SUBTERRANEAN HEAT is an old hypothesis. Cosmogonists have imagined that the whole earth was once in a state of fusion; and that, as a result of attraction and rapid rotation on its polar axis, it assumed in its semiliquid condition, the form of an oblate spheroid.

The *sources of proof* upon which the existence of a high temperature within the interior of the earth is made to depend are:—1. The progressive rise of the thermometer as we descend into mines and other deep excavations, below the level of the sea. 2. The high temperature of the water which issues from Artesian wells carried to a great depth. 3. The high temperature of natural thermal baths and springs. 4. The phenomena which accompany volcanic eruptions and earthquakes.

In considering these facts it is necessary to bear in mind that we know but little concerning the structure of the earth, and it cannot be said that we have yet penetrated into the interior.

The depth to which we have actually penetrated the crust of the earth below the level of the sea is barely *half a mile; i. e.* in the deepest mine, not more than 1-16,000th part of the earth's diameter! and the greatest depth at which the temperature of the sea has been measured is 12,420 feet. This is about two miles, or only 1-4000th part of the earth's diameter.

To whatever conclusion we may come respecting the existence of subterranean heat, it appears certain, so far as our present means of observation will enable us to judge, that all the phenomena connected with temperature on the surface of the earth are explicable on the supposition that they are entirely due to the balance which exists between the heat received from the sun, and that which is radiated into space or conducted downwards into the strata. This is proved by the fact, that daily and monthly changes of temperature correspond, *cæteris paribus*, with the position of the sun: and the mean annual temperature, making due allowance for local circumstances, is dependent on the quantity of solar heat received. Probably a century of accurate observations, made with the thermometer, would show that our globe had become neither perceptibly hotter nor colder. Some have asserted that the climate of Europe has become colder, while others have thought that it has become hotter during the last 2,000 years. Had the thermometer been known to the Romans, and registers kept, we might now have before us the elements for solving this interesting question; but in the absence of correct data, the two conflicting opinions may perhaps be fairly regarded as neutralising each other. Signor Libri, of Florence, has shown, by comparing our modern thermometers with one of those early instruments constructed by the Academia del Cimento, in 1667, that no change whatever had taken place in the climate of that part of Italy during the last 200 years. According to Arago, the temperature of the earth cannot have varied so much as the one three-hundredth part of a degree of Fahrenheit since the days of Hipparchus, a period of about 2,000 years, or there would have been a perceptible change in the length of the day. This view is founded on the assumption, that a heated spherical solid contracts in cooling, and that by a diminution in the bulk of the earth, there would be a decrease in the length of the polar and equatorial axes, and consequently a measurable difference in its period of revolution. The contracting power of the earth in cooling is, for the purpose of this calculation, assumed to be equal to that of glass. This principle is correct to a certain extent, but some recent observations, made on the cooling of spheroidal masses from a state of fusion, show that so soon as an external coherent crust is once formed, there is no longer a contraction in bulk, but a vacuum actually occurs in the interior of the sphere.*

The following conclusions appear to be justified by the facts hitherto ascertained respecting the heat of the globe: — 1. That at a certain depth below the surface of the earth, there is a source of heat which progressively affects the thermometer as we descend. 2. That this interior heat cannot be derived from the sun or from local chemical changes. 3. That it does not directly affect climates or seasons, or perceptibly influence the temperature of the surface of the earth, the depths of the ocean, or the atmosphere floating above them. 4. That the vicissitudes of climates, seasons, and cycles of years, are due entirely to solar influence. 5. That this influence, even at a maximum, does not penetrate to a greater depth than the 1-400,000th part of the earth's diameter. 6. That although we have positive evidence of the existence of subterranean heat, we can neither measure its degree, nor, at present, determine its exact ratio of increase downwards into the interior. 7. That there is not the slightest evidence to show that the earth is gradually cooling from a high temperature, or that, within the last 2,000 years, its temperature has undergone any increase or diminution.

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* The mean *density* of the earth, as determined by pendulum experiments, is nearly six times that of water, or 5·66, according to the experiments of the late distinguished philosopher, Mr. Francis Bailey; but the average density or specific gravity of the rocky masses composing the crust of the globe, is less than three times that of water, — about 2·5 to 2·8. The density of the earth, therefore, is much less than that of all the common metals, and falls between the specific gravity of Tellurium (6·1) and Titanium (5·3). Hence we have reason to believe, that while the substances composing the mass of the globe are heavier than those which form the surface, they are considerably lighter than tin, iron, lead, and other common metals. It was this result, combined with the theory that the density of bodies should increase as we approach the centre of the earth, which led the celebrated philosopher, Professor Leslie, to suppose that the globe must be a hollow sphere, and that we are living upon a shell, the thickness of which bears only a very slight proportion to the earth's diameter!

Admitting that we are living upon the mere shell of a heated mass of matter, some thousands of miles in thickness, we have no evidence to show that this is allowed to exert any influence except for beneficial purposes. Without this internal heat, that which is transmitted to us from the sun would be continually conducted downwards into the interior, and be lost. The invariable stratum, therefore, appears to act as a kind of barrier to the too rapid transmission of this solar heat, and thus preserves to the superficial strata, that temperature which is necessary to the support of animal and vegetable existence. Hence that which some philosophers have been inclined to regard as a great element of destruction, may, in reality, be the means of our preservation.

PART II.

THE ELEMENTARY PRINCIPLES OF ASTRONOMY.

Astronomy is the science which treats of the natures, motions, and mutual relations of the heavenly bodies.

Chapter I.

The General Appearance of the Heavens.

If during a clear night, and from a spot whence the horizon is visible, we contemplate with attention the face of the heavens, it will be observed to undergo a continual change. Some stars will be seen ascending, others descending; some, as the Pole-star, and the stars of the Great Bear, never touch the horizon in these latitudes. During these movements, the relative position of the stars undergoes no change. They describe parallel circles which are of smaller extent, in proportion as they are nearer to a certain point, which appears fixed. In fact the general appearance of the heavens is that of a vast concave sphere, turning on two imaginary fixed points, diametrically opposite to each other. These imaginary fixed points are called the Poles; the pole above our horizon is called the *North Pole;* the pole opposite to it the *South Pole.*[*]

Each star attains its greatest height, or *culminates,* at the point in which its apparent path intersects the meridian, an imaginary great circle drawn through the poles and the zenith. (See Defs. 6, 27.)

A very few of the heavenly bodies will be seen, if observed for any length of time, to change their position relatively to the other stars; these are the sun, the moon, the *planets,* or *wandering stars,* and *comets.*

The moon makes a complete circuit of the heavens in the course of a month; and though she appears to rise and set daily like the stars, and to move from east to west, yet, compared with them, she will be found to have a retrograde or backward motion towards the east to the extent of about 13° daily; that is, if on any night she be seen in conjunction with a fixed star, the next night she will appear about 13° to the eastward of that star, the following night 26°, and so on.

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[*] La Place, Système du Monde, ch. i.

The sun has a similar apparent retrograde motion, though only to the extent of about 1° daily. He consequently takes a whole year to complete the circuit of the heavens.

The planets, as compared with the fixed stars, appear to move, sometimes towards the east, sometimes towards the west; and, at other times, for several nights together, they will appear stationary.

Owing to the apparent retrograde motion of the sun, every fixed star will rise about four minutes earlier each successive day. (See Defs. 56, 57, 61.) It will be seen that, owing to this cause, every star (with the exception of the *circumpolar* stars, or those which never set in our latitude) will at some period of the year appear just above the horizon at sunset, and will then be seen to the best advantage during the night. It will then continue to rise earlier by four minutes every sucessive day, and will of course be visible for a correspondingly shorter period during the night, until at length it will rise simultaneously with the sun, and will become invisible during the whole or the greater part of its course*, its light being obscured by the sun's greater brightness. Subsequently it will come upon the horizon earlier than the sun, and will in consequence be visible before sunrise. After the completion of a year it will rise at sunset as before.

It has been already shown, (*Part* I., *Chap*. 3.), that the apparent diurnal motion of the heavens is caused by a real rotation of the earth on its axis, and that the apparent motion of the sun arises from a real motion of the earth round that body. It will be shown in a subsequent chapter, that the planets, like the earth, revolve round the sun, and that the apparent irregularity of their movements arises from the circumstance that the earth itself, from which our observations are made, is continually changing its position in space.

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* If the star be nearer the pole than the sun, or, in other words, if its declination be greater, it will describe a larger arc above the horizon, and will consequently be above the horizon longer than the sun. It will. therefore, be invisible only during the greater part of its course. If its declination be not greater than that of the sun, it will, when rising with the sun, be invisible during the whole of its course.

It will also be shown that the apparent motion of the moon is caused by a real motion round the earth, similar to that of the latter body round the sun. It has been ascertained that some of the planets, also, are accompanied by moons, or, as they are usually termed, *satellites*, that is, *attendant stars*.

Chapter II.

Of the Situation of the principal Constellations, and the Manner of distinguishing them from each other.

The distance of the fixed stars from the earth is so great, that the most powerful telescopes have been unable to ascertain any apparent magnitude even of the brightest among them. As, however, to the unassisted eye, a distant light always appears large in proportion to its brightness, astronomers have divided the stars into orders of *magnitude*, which might more correctly be termed orders of splendour. The brightest stars are called stars of the first magnitude; the next to these in splendour, stars of the second magnitude, and so on. Those of the sixth magnitude are but just perceptible to the naked eye. Those which cannot be discerned without the aid of telescopes, are termed *telescopic stars*, and are divided into the seventh, eighth, &c. magnitudes.

There are 20 stars of the first magnitude, 76 of the second, 223 of the third, 510 of the fourth, 695 of the fifth, and 1604 of the sixth magnitude. Consequently the number of fixed stars visible to the naked eye is 3128. It will be observed that more than half of these are of the sixth magnitude, and that the number of stars of each magnitude rapidly increases as the magnitudes diminish. This rule holds good with the telescopic stars also.

The stars were in early times divided into different groups, called *constellations*. (See Def. 91.) The names given by the ancients to these groups have for the most part been retained to the present day. A list of the constellations is given in the first part of this work.

The stars composing each constellation are noted (see Def. 94,) by the letters of the Greek alphabet, α, β, γ, &c., in the order of their magnitudes; and when the number in any constellation is so great as to need further notation, by the letters of our alphabet, and by numerals. Several of the principal stars are still known by the names given them by the Arabian astronomers: thus, α Orionis is called *Betelgeux*, β Orionis *Rigel*, &c.

A knowledge of the principal constellations in the heavens will be an useful acquisition to the student, and this knowledge will be best obtained by noting the hour at which they come to the meridian at different times of the year.

The time of culminating of each of the zodiacal constellations is given on the opposite page, and likewise the semi-diurnal arc, by which the times of rising and setting may be ascertained with sufficient accuracy for practice. In the following description, the principal constellations which culminate with the zodiacal constellations are pointed out, and their relative positions with respect to each other are shown; so that the time of their coming to the meridian on any given day of the year may be found without difficulty.

The Constellations and Principal Stars (visible at London) which culminate with the Zodiacal Constellations, are the following, commencing from the Southern Horizon.

1. With Aries (α):—The neck of Cetus, Triangulum, γ Andromedæ (*Almach*), the head of Perseus, and the feet of Cassiopeia; α Ceti (*Menkar*), Musca, the head of Medusa, the body of Perseus, and the tail of Camelopardus, culminate three-quarters of an hour after α Arietis.

2. With Taurus (α, *Aldebaran*):—Part of Eridanus and Camelopardus. α Persei (*Algenib*) culminates an hour and a quarter, and the Pleiades three-quarters of an hour before it; β Orionis (*Rigel*), and α Aurigæ (*Capella*) about half an hour after it.

3. With Gemini (α, *Castor*):—Canis Major, Monoceros, Canis Minor, and Lynx. α Canis Majoris (*Sirius*) culminates three-quarters of an hour before Castor; α Canis Minoris (*Procyon*) about six minutes after it.

A TABLE of the time of *culminating* of the Zodiacal Constellations on the first Day of every Month, and the Semi-diurnal Arcs at London.—N.B. The time is reckoned from noon to noon.

Zodiacal Constellations.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	S. Diur. Arc.
Aries, α.	7¼	5	3¼	1¼	23½	21½	19	17	15	13¼	11½	9½	8¼ H.
Taurus, α.	9¾	7½	5¾	3¾	1¾	23¾	21¾	19¾	17½	16¾	14	11¾	7½ H.
Gemini, α.	12½	10½	8¾	6¾	4¾	2¾	0¾	22½	20½	18¾	17	15	9¾ H.
Cancer, α.	14	11¾	10¼	8¼	6½	4¼	2	0	22	20¼	18½	16½	7¼ H.
Leo, α.	15¼	13	11¼	9¼	7½	5½	3½	1¼	23¼	21¼	19½	17½	7½ H.
Virgo, α.	18½	16¼	14½	12½	10¾	8½	6½	4¾	2½	0¾	22¾	20½	5¼ H.
Libra, α.	19¾	17½	15¾	14	12¼	10	8	6	4¼	2¼	0¼	22¼	4¾ H.
Scorpius, α.	21½	19¼	17½	15½	13¾	11¾	9¾	7¾	5¾	3¾	2	23¾	3½ H.
Sagittarius, δ.	23¼	21¼	19¼	17¼	15½	13½	11½	9½	7½	5½	3¾	1¾	3 H.
Capricornus, β.	1½	23	21¼	19¼	17½	15½	13½	11¼	9½	7½	5¾	3¾	4¾ H.
Aquarius, α.	3¼	1	23¼	21¼	19¼	17¼	15¼	13¼	11¼	9½	7½	5½	5¾ H.
Pisces, α.	7	4¾	3	1	23¼	21¼	18¾	16¾	14¾	13	11¼	9¼	6¼ H.

4. With Cancer (α, *Acubene*):—The head of Hydra, the tail of Lynx, and the head of the Great Bear.

5. With Leo (α, *Cor Leonis* or *Regulus*):—Part of Hydra, Leo Minor, and the shoulder of the Great Bear. α and β Ursæ Majoris culminate an hour after Regulus.

6. With Virgo (α, *Spica*):—The middle star in the tail of the Great Bear (ζ Ursæ Majoris, *Mizar*). Coma Berenices and Cor Caroli culminate an hour before Spica; α Bootis (*Arcturus*) about an hour after it.

7. With Libra (α, *Zuben el Chamali*):—The left leg and head of Bootes. The head of Serpens, and Corona Borealis culminate three-quarters of an hour after α Libræ.

8. With Scorpius (α, *Antares*):—The left arm of Ophiucus, and the club and body of Hercules.

9. With Sagittarius (δ):—Scutum Sobieski, the left hand of Hercules, the head and body of Draco, and the pole of the ecliptic. α Lyræ (*Vega*) culminates a quarter of an hour after δ Sagittarii.

10. With Capricornus (β, *Deneb Algedi*):—The bow of Antinous, Vulpecula et Anser, and the neck and body of Cygnus. α Aquilæ (*Atair*) comes to the meridian half an hour before β Capricorni; the head of Delphinus a quarter of an hour after it.

11. With Aquarius (α):—The feet of Pegasus, Lacerta, and the head of Cepheus. α Piscis Australis (*Fomalhaut*) culminates three-quarters of an hour after α Aquarii; α Pegasi (*Markab*) and β Pegasi (*Scheat*) an hour after it.

12. With Pisces (α):—As this star culminates with the head of Aries, the stars culminating with it will be the same with those mentioned as culminating with Aries. α Arietis culminates a few minutes after α Piscium; β and γ (*Mesartim*) a few minutes before it. α Andromedæ (*Alpherat*) comes to the meridian nearly two hours, β Andromedæ (*Mirach*) about an hour after it.

If the student observe the heavens in the month of January, about ten o'clock in the evening, when the stars are shining brightly, he will perceive towards the south the group called the Pleiades: to the left hand of this, a little lower down, is Aldebaran, a remarkable star of a reddish colour in the head of the Bull, close to which star, a little above on the right hand, lie the Hyades. (*Plate* IX. *Fig.* 1.)

Further to the left hand and a little higher than the

Pleiades, is the constellation Auriga, which is represented in *Plate* IX. *Fig.* 2.

The highest star towards the right hand is Capella, a star of the first magnitude.

A line drawn from Capella through the star marked β in the northern horn of the Bull, and continued in the direction of the horizon, will pass through the middle of Orion. This, the most brilliant and conspicuous of the constellations, will readily be recognised from the figure (IX. 3.). It contains two stars of the first, and four of the second magnitude; viz., α, *Betelgeux*, in the right shoulder, and β, *Rigel*, in the left foot, both of the first magnitude; γ, *Bellatrix*, in the left shoulder, and δ, ε, and ζ, forming the belt, all of the second magnitude.

About 26° from Betelgeux, towards the left hand, is α Canis Minoris, or Procyon, a star between the first and second magnitudes. Nearer to the horizon, and forming an equilateral triangle with Betelgeux and Procyon, is α Canis Majoris or Sirius, the brightest of the fixed stars, of a brilliant white colour.

To the left hand of Auriga, and forming an almost equilateral triangle with Capella and Aldebaran is α Geminorum, or Castor; near it, a little below on the left hand, is β Geminorum, or Pollux, both of the second magnitude. Four stars will be observed in a line, bisecting at right angles a line drawn between Bellatrix and Castor; these are the four feet of Gemini.

To the right hand of Auriga, above the Pleiades, and in a line with Castor and Capella is α Persei, or Algenib, a bright star in the breast of Perseus; further to the right is α Andromedæ or Almach; these two stars with β Persei or Algol, a star in the head of Medusa, form a right-angled isosceles triangle, Algol, the star in the right angle, being the nearest to the Pleiades. A line drawn from the Pleiades through Algol will pass through Cassiopeia. This constellation is usually described by the figure of an inverted chair; its five principal stars, which are of the third magnitude, form a capital W, roughly made.

To the right hand of the Pleiades, at a distance of about 22°, is α Arietis, a star of the second magnitude; a line drawn from the Pleiades through this star will pass through α Pegasi, or Markab. The constellation Pegasus is very remarkable: it contains four stars of the second magnitude; three of which, α, or Markab; β, or Scheat; and γ, or Algenib, together with Alpherat in the head of Andromeda, also of the second magnitude, form a large square. The highest star towards the right is Scheat; it may be known by a kind of isosceles triangle formed by three stars, on its right hand. A line drawn from Algenib through Markab will pass a little above ϵ Pegasi, the remaining star of the second magnitude in that constellation. A line joining Alpherat and Almach will pass through β Andromeda or Mirach. (See *Plate* IX. *Fig.* 4.)

If the student stand facing the north, he will perceive Ursa Major, or the Great Bear, to be after Orion the most conspicuous constellation in the heavens. Being one of the constellations which never set in our latitude, it may be seen every fine starlight night. In *Plate* IX. *Fig.* 5. are represented the seven most remarkable stars in this constellation, as seen when it is below the Pole: five of these are of the second, one of the third, and one of the fourth magnitude. The two marked a and β are called the Pointers, because a line drawn from β through α passes a little to the left of a bright star of the third magnitude, distant about 1°. 31′ from the north pole of the heavens, and called, in consequence, the *Pole Star.* This is the principal star in the constellation Ursa Minor.

Ursa Minor, or the Little Bear, closely resembles the Great Bear, inverted; its stars, however, are far inferior in brightness. An imaginary line bisecting at right angles the line which joins α and δ in the Great Bear will pass between β and γ in the Little Bear.

A knowledge of these constellations will assist the student in ascertaining the position of others. For instance, the tail of Draco lies between Ursa Major and Ursa Minor. An imaginary line drawn through δ and γ in Ursa Major, southward, will pass through the brightest star in Leo Minor, and through Regulus, a star of the first magnitude in Leo Major. Regulus is easily distinguishable, being the southernmost of four bright stars.

From the foregoing description, with the assistance of a celestial globe or atlas, it is presumed the learner may acquire a knowledge of the principal constellations which appear in the heavens during the winter. Those which present themselves in the summer are less conspicuous, but the most remarkable among them may be distinguished by the aid of the following description:—

If any one observe the heavens about ten o'clock in the evening at the beginning of May, he will see the Great Bear near the zenith. To the right hand of the pointers in the Great Bear, and near the horizon, are Castor and Pollux, and farther to the right hand is Auriga. These have been already described. The line above mentioned, drawn from δ and γ in Ursa Major, through Leo Minor and Regulus, will, if continued, pass through Cor Hydræ. Near the horizon, to the right of Cor Hydræ, is Procyon in Canis Minor: these three stars form a nearly isosceles triangle, of which Procyon is the vertex. At nearly the same distance from Cor Hydræ on the left, that Procyon is on the right, will be found the constellation Crater or the Cup; beyond Crater, in the same direction, is Corvus, the Crow, forming a roughly drawn parallelogram. A line drawn from α in the Great Bear through γ in the same constellation, will pass by Coma Berenices, and afterwards through Spica Virginis, a star of the first magnitude in the Virgin's left hand. Spica Virginis, Arcturus, the principal star in Bootes, also of the first magnitude, and Deneb, in the Lion's tail, of the second magnitude, form an equilateral triangle, of which Arcturus is in the most elevated angle, while Deneb is situated towards the right hand. Leo, Virgo, and Coma Berenices, with Arcturus and Cor Hydræ, will easily be recognised from the representation. (*Plate* IX. *Fig.* 6.)

A line connecting the first and third stars in the tail of the Great Bear (ε and η) will pass through Corona Borealis, the six principal stars of which form a semi-ellipse, one star being of the second, the other five of the fourth magnitude. A line drawn from Arcturus through Corona Borealis will pass through the body of Hercules, beyond which, in the same direction, is the bright star Vega, in the constellation Lyra. Below Corona Borealis is Serpens; below Hercules Ophiuchus, or the Serpent-holder. When Hercules or Corona Borealis is on the meridian, Arcturus will be on the right hand, Vega on the left. Vega, Atair, or α Aquilæ, and the head of Delphinus or the Dolphin, form an isosceles triangle, the vertex of which is Vega. Atair is easily recognised, being a star of the first magnitude, lying between two of the third magnitude, all three being near together, and in a straight line; the Dolphin lies to the left hand of Atair, rather nearer the Pole, and contains five stars of the fourth magnitude, arranged in the form of a capital P roughly made, the loop of the letter being turned towards Vega. Above the Dolphin, and to the left hand of Vega, is Cygnus, or the Swan, a remarkable constellation in the Milky-way, in the form of a large cross; it contains one star of the second magnitude, called Deneb. Below Cygnus is Pegasus, which has been already described.

On the convex surface of the celestial globe the figures of the constellations, and the positions of the stars generally, are reversed, those which appear to the right hand on the globe being to the left hand in the heavens, and *vice versa*. In the preceding account their positions are given as seen in the heavens.

The Galaxy, or Milky-way, is a luminous band, which may be seen any fine evening stretching across the sky from horizon to horizon. It forms "a zone, completely encircling the whole sphere, almost in a great circle. It is divided in one part of its course, sending off a kind of branch, which unites again with the main body, after remaining distinct for about 150 degrees. It is found, when examined through powerful telescopes, to consist entirely of stars scattered by millions, like glittering dust, on the black ground of the general heavens."*

CHAPTER III.

The Method of measuring the Altitudes, Zenith Distances, &c. of the Heavenly Bodies; including a Description of the Astronomical Quadrant, Circular Instrument, Transit Instrument, Micrometer, &c.

THE ASTRONOMICAL QUADRANT.

THE annexed figure is a representation of the astronomical quadrant. The arc BH, which is usually constructed of brass, is a quadrant or fourth part of the circle whose centre is C, and whose radius is equal to CH or CB. It is divided into ninety equal parts, or degrees, and each degree into as many smaller parts as the size of the instrument will admit. The quadrant is so placed that the line CB shall coincide with a plumb-line, CP hanging from C, that is, that CB shall be vertical, CH horizontal, and in the plane of the horizon. T*t* is a telescope, moveable about the centre C.

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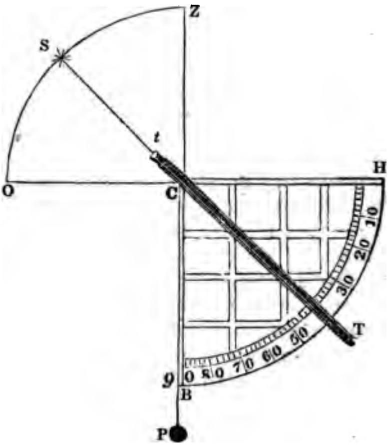
* Herschel's Astronomy, s. 253.



Now, if the plane of the instrument be made by proper adjustment to coincide with the plane of the meridian, and the plumb-line CP to coincide with CB, that is, to hang accurately over the division marked 90°, it is obvious that if the telescope be directed towards a star S in the plane of the meridian, the number of degrees between H and T on the quadrant will mark the star's altitude OS on the meridian, and the number of degrees between T and B will mark its zenith distance SZ; for the imaginary quadrant OZ of the meridian is supposed to be similarly divided to the quadrant HB, and to contain 90° between the horizon at O and the zenith Z. If the star be in the horizon, the telescope will coincide with CH; if the star be in the zenith, the telescope will coincide with CB. In the figure annexed the telescope is directed towards a star, having about forty degrees of altitude.

The quadrant may, of course, be placed in the plane of any vertical great circle; it will then measure altitudes in that circle.

THE CIRCULAR INSTRUMENT.

The astronomical quadrant is now generally superseded by the circular instrument, a representation of which is given in *Plate* VI.

In this instrument the quadrant is replaced by a complete vertical circle, to which the telescope CD is attached, coinciding with its diameter. The semicircle on either side of CD is divided into two quadrants, which are graduated, as the quadrant just now described, the division 90° being marked at either extremity of the diameter which coincides with the telescope, the division 0° at either extremity of the diameter perpendicular to it. The circle and telescope move together round the centre.

When the telescope is horizontal, that is, in the plane of the horizon, the divisions marked 0° will be at Z and M. When it is vertical, the divisions marked 90° will be at those points. If the telescope be directed to any star, the arc of the circle intercepted between M and the lower part of the telescope will show the star's zenith distance; the arc intercepted between M and the lower division marked 0° will show its altitude. From the meridian altitude of a star at a place of known latitude, the star's declination and polar distance may easily be deduced.

The telescope CD is provided with a reflecting eye-piece, to admit of the convenient observation of stars in or near the zenith. At M is a vernier[*], by which, with the aid of a microscope, the position of the star is read off with great

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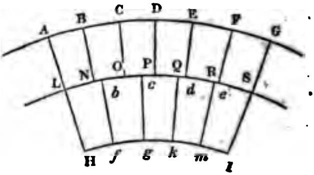
[*] "A vernier, (so called from the name of its inventor), is a small moveable scale, running parallel with the fixed scale of a quadrant or other instrument, and having the effect of subdividing the divisions of that scale into more minute parts. Let AG be any proportion of the limb, or circular part, of a quadrant; for example, half a degree divided into six parts, AB, BC, &c., of five minutes each. Let HI be another limb of equal extent, divided into five parts. In consequence of the relation of these divisions, we see that the line *fb* will be further advanced than N by a fifth part; *gc* by two-fifths; *kd* by three-fifths; *me* by four-fifths, and IS by five-fifths, or a whole division. By this means each of the divisions, AB, BC, may be divided into five parts or minutes, by shifting the moveable limb (or *vernier*) HI to any part of the quadrant where the subdivision is required." (*Library of Useful Knowledge, Natural Philosophy*, Vol. I. Glossary.) The above is a description of the original form of the vernier. As it is at present constructed, the number of subdivisions of the moveable scale exceeds that of the subdivisions of the fixed scale by one, instead of the contrary.



minuteness. The circle is moved by the screw G, slowness of movement in the instrument being essential to an accurate adjustment of it.

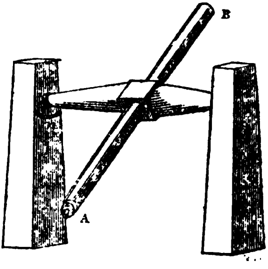
The base of the instrument has a horizontal motion, produced by turning the screw at O. This circular base is placed in an accurately horizontal position by means of the screws E, E, E, any error in its level being detected by means of the two spirit-levels S, S, at right angles to each other. By means of the degrees marked on this horizontal circle the azimuths of celestial objects are obtained.

The object-glass of the telescope both in this instrument and in the quadrant being a wide field, capable of admitting a star in several different positions, it is necessary that some means should be found of accurately marking its centre. For this purpose wires are extended across it, both in a horizontal and in a vertical direction, two of which intersect exactly in the centre. Care is taken in observation that the star be accurately on the point of intersection of these two wires.

The astronomical quadrant and the circular instrument are sometimes permanently fixed to a horizontal wall in the plane of the meridian, and are then called respectively the *mural quadrant* and *mural circle*.

THE TRANSIT INSTRUMENT.

The transit instrument is, as its name imports, an instrument for marking the time at which a heavenly body crosses the meridian of the place of observation. It consists of a small telescope, A B, turning upon a pivot in the plane of the meridian. Across the object-glass are five equidistant vertical wires, and one horizontal wire, the middle vertical wire intersecting the horizontal in the centre of the object-glass. The imaginary line joining the centre of the eye-glass with the centre of the object-glass is called the *line of collimation*, and, when the instrument is properly adjusted, lies in the plane of the meridian.



By means of the index *n*, which marks the angle of elevation of the telescope, the instrument is so adjusted, that the star, whose transit is to be observed, shall pass as nearly as possible across the centre of the object-glass. At the moment at which it crosses the middle wire, it is in the act of culminating or passing the meridian. This instant is immediately noted by the clock. To guard against error, however, the moments of its passing all five wires are noted.

The quadrant or circular instrument may, when placed in the plane of the meridian, be made to serve the purpose of a transit instrument, since their object-glasses are, like that of the transit instrument, furnished with equidistant vertical wires, one of which passes through the centre.

THE MICROMETER.

The micrometer is a contrivance for measuring the distance between closely adjacent stars, or the diameters of the sun, moon, and planets. It consists of two parallel wires, one at least of which must be moveable, stretching across the object-glass of a telescope. In observing the breadth of the disc of any body, the instrument is so placed that one of the wires shall touch the circumference of the body on one side; the other wire is then moved by a screw until it touches the circumference on the other side. The portion of the object-glass occupied by the body is thus found, and the power of the telescope being known, the arc occupied by its diameter in the heavens is known also. In a similar manner the distance between two stars may be found, viz. by so adjusting the micrometer that one star shall be on each wire, care being taken that the line joining the stars be at right angles to the wires.

It is sometimes necessary to note not only the distance between two adjacent stars, but also their relative positions. For this purpose* a fixed wire AB is stretched across the centre C of the object-glass. Another wire DE is moveable round the centre C. The circle ABD is divided into degrees, minutes, &c.

The telescope being so directed that one of the stars lies in the centre C, the wire DE is turned round by a screw until it come on the other star s. The number of degrees and smaller divisions contained in the arc A E is then noted down. The distance C S may be found by the micrometer above described. It will be seen, that by means of these two instruments it is possible to note with exactness the relative position of any two stars, which are near enough to each other to come at once within the object-glass of the telescope. The micrometer, as was mentioned above, is used for several purposes: the principal use of the instrument last described will be shown in the following chapter

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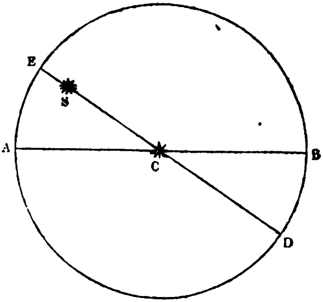
* Arago: Annuaire du Bureau des Longitudes, pour l'an 1834, p. 252.



CHAPTER IV.

Of the real and apparent Motions of the Stars; of their Colours; of Variable Stars; and of Astral Systems.

THE statement that the so-called Fixed Stars undergo no change of position is not accurately correct: in the course of an attentive observation through a long series of years, very slight changes are observed, some of which are to be ascribed to real motions of the stars themselves, the rest to apparent motions, produced by other causes. The causes of apparent motion are, the Precession of the Equinoxes, the Nutation of the Earth's axis, Aberration, and Parallax.

PRECESSION OF THE EQUINOXES.

It has been already stated (Def. 64), that the point of intersection of the ecliptic with the equinoctial has a retrograde motion of 50·1″ in a year, and that consequently a revolution of the equinoctial points will be completed in about 25,868 years. During this motion the ecliptic and equinoctial preserve their common centre, and their axes remain inclined to each other at a constant angle of 23½ degrees. Consequently the pole of the equinoctial will in this period of 25,868 years describe around the pole of the ecliptic, as centre, a circle of 23½ degrees radius. Hence every star upon or close to this circle will in its turn become the pole-star for the time being, that is, will be the nearest to the north-pole of the equinoctial. The present pole-star is *α* Ursæ Minoris, which is about 1° 31′ from the pole. Its nearest approach to the pole will be when its longitude is 90°, which will be in the year 2103. It will then be within half a degree of the pole. After the lapse of about 12,000 years, *α* Lyræ will be the pole-star, being then within about 5° of the pole.

Owing to the precession of the equinoxes, the right ascension and declination of the stars are continually varying, inasmuch as they are measurements depending on the equinoctial, which is continually changing its position: the longitude of every star receives an uniform annual increase of 50·1″, since the point on the ecliptic from which it is measured retires yearly by that distance; while the latitude of the stars, being independent of the equinoctial, remains unaltered.

The effect of the retrograde motion of the point of intersection of the equinoctial with the ecliptic is to bring the sun earlier upon the equinoctial than would otherwise be the case. It is for this reason that this motion is termed the *precession* of the equinoxes. *

The cause of precession is as follows: the earth, being an oblate spheroid, thicker at the equator than at the poles, may be roughly represented by a perfect sphere, surrounded by a broad band of matter, inclined to the sun's orbit at an angle of 23½°. The attraction of the sun and moon upon this band tends to draw it into the planes of their own motion. The rotatory motion of the earth, however, prevents their doing so, and the combined action of the two causes results in a slow retrograde motion of the axis of the equator round the axis of the ecliptic, one revolution of which is, as before stated, completed in 25,868 years. †

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* For the difference of length between the tropical and sidereal years, see Defs. 62, 63.

† The phenomenon of the precession of the equinoxes was first observed by Hipparchus in the second century B. C. The true cause of it was discovered by Sir Isaac Newton.

It was stated above that the inclination of the ecliptic to the equator is constant. This is not absolutely correct; owing to the attraction of the planets, its inclination diminishes by ½″ yearly, or 1° in 6900 years. After a period this diminution will cease, and the inclination will begin to increase again; the variation thus produced can never, as has been proved by Laplace exceed from one to three degrees.

NUTATION.

The plane of the sun's motion preserving always nearly the same inclination to the equator, the part of the precession owing to the sun's action is the same every year. The moon's orbit, on the contrary, is at one time inclined above ten degrees more to the equator than at another: hence the part of the precession arising from the moon's action varies in quantity, though its *mean* annual value is constant.* This variation causes the pole of the equinoctial to describe a small ellipse around its mean position as centre. This ellipse is completed in a revolution of the moon's nodes (see page 213.), that is, in 18 years and 228 days. The greater axis is in the solstitial colure, and subtends an arc of about 20″; the lesser is in the equinoctial colure, and subtends an arc of about 15″. The rolling or *nodding* motion here described is called the *nutation* of the earth's axis, and of course produces a corresponding apparent motion in the stars, as observed from the earth's surface.

ABERRATION.

The nature and cause of the *Aberration of Light* have been explained in Def. 122. From an examination of the figure there given, it will be seen that the stars *from* which the earth is moving must appear to a spectator on the earth's surface to be higher than they actually are, those *towards* which she is moving, lower. Since this change of apparent position varies with the earth's motion in its orbit, which is elliptical, it will easily be seen that the annual path described by the apparent position of a fixed star about its real position must be also elliptical: the longer axis of this ellipse subtends an angle of about 40″.†

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* Bradley, as quoted in the Hist. of Astronomy, L. U. K., p. 92.

† Nutation and Aberration were first observed, and their causes explained, by Bradley, about the middle of the last century.

PARALLAX. DISTANCE OF THE NEAREST FIXED STARS.

The phenomenon of parallax has been described in Def. 86. From an examination of the figure there annexed, it will be seen that the greater the distance of a star from the earth, the smaller is its parallax. So great is the distance of the fixed stars, that until lately astronomers failed to detect parallax in any of them. A few years ago, however, Bessel discovered the parallax of 61 Cygni to be about one-third of a second, since which time Struve has discovered a parallax of one-fourth of a second in *α* Lyræ, and Professor Henderson of Edinburgh a parallax of an entire second in *α* Centauri. This last, which is in all probability the nearest of the fixed stars, is hence calculated to be at a distance of above nineteen millions of millions of miles; and consequently light, which travels at the rate of 192,000 miles in a second, and which takes but eight minutes to pass from the sun to the earth, must occupy upwards of three years in travelling hither even from the nearest of the fixed stars. This distance is far too great to admit of the possibility of their shining by the reflection of the sun's light: it follows therefore that some, at least, of the fixed stars must shine by their own light, while others are probably enlightened by these, as the earth and planets are by our sun.

PROPER MOTIONS. MULTIPLE STARS.

Upon a careful examination of the heavens, it is found that great numbers of the stars are arranged in groups of two, three, or more, respectively, several of which groups are composed of stars so close to each other, that to the naked eye or to telescopes of inferior power, they appear to be single stars. Among the most remarkable of these are Castor, Rigel, the Pole-star, and Vega. This apparent proximity of stars to each other may arise either from real proximity, or from their being nearly in a line as seen from the earth. The number of groups, however, is far greater than can be accounted for on the latter supposition only. It therefore follows that there must be in the heavens numerous groups of two, three, or more stars in actual proximity to each other. Struve has calculated that of 311 pairs of stars, the constituents of which have been observed to be within 4″ of each other, 310 must be considered to be pairs of actually approximate stars: of 653 pairs, whose constituents are within 32″ of each other, 605 are really approximate.[*]

Triple stars, or combinations of three, are much more rare than binary stars. Struve has, however, specified 11 such combinations, each within the space of 32″, of which 10 at least must be considered to be cases of actual proximity. He has further recorded 116 triple stars, in which the proportion of actual proximity is not so great. Cases of quadruple, and even higher combinations, have also been observed. Of 140,000 stars examined by Struve, one in forty were found to be multiple stars.

The constituents of multiple stars are seen to vary their relative position from time to time; and from an attentive and continued examination of these variations by means of the two instruments described at the end of the last chapter, it is found that all those whose orbits have been accurately ascertained follow the same law of motion that is found in our own system; viz., that they describe elliptical orbits about each other, and that the line uniting any pair passes over equal areas in equal times. (See Part I. Ch. IV.) Now, it can be proved, that no other law of attraction than that of gravitation can produce motion of this kind. Hence it follows that all the stars which have been accurately observed, and probably all stars whatever, are governed by the same law of gravitation which regulates our own system.

The four following systems have completed an entire revolution since their motion was first observed: their periods are annexed[†]: —

η Coronæ revolves in	43 years.
ζ Cancri	54
ξ Ursæ Majoris	60
p Ophiuchi	81

It is not, however, necessary to wait for a complete revolution. The orbit and period of a star may be calculated from a few observations. Thus it is calculated that σ Coronæ has a period of 287 years; γ Virginis, of 629 years; γ Leonis, of

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[*] The stars here spoken of include all the double stars from the North Pole to 15° south of the equator, in which neither constituent is much smaller than can be discerned by the naked eye. The proportion of cases of actual to those of mere optical proximity, is not so great for smaller stars similarly situated.

[†] Nichol, Architecture of the Heavens, p. 91.

1200 years. Others are probably of still longer periods: the period of Mizar round Alcor is supposed to be about 190,000 years. Others again have very brief periods. In fine, there probably will be found in the heavens every variety of system, both as to number of constituents, real and relative magnitude, and length of period. Few of the higher combinations have been accurately examined: the periods of one or two triple stars have, however, been discovered; and one quadruple star (ε and 5 Lyræ) has been observed to consist of two pairs, the constituents of each pair revolving round each other, while the pairs themselves revolve round some point intervening between them.

COLOUR OF THE STARS.

The stars do not all shine with the same colour. "Among those of the first magnitude, for instance, Sirius, Vega, Altair, Spica, are white; Aldebaran, Arcturus, Betelgueux, red; Capella and Procyon, yellow." * Among the double stars every variety of colour is found: but some remarkable peculiarities are found in the association of these colours. In a list of fifty-six pairs, given by Arago, only seven pairs are found, the constituents of each of which are of the same colour: this colour is in every case some shade of blue. "Many of the double stars exhibit the curious and beautiful phenomenon of the contrasted or complementary colours. In such instances the larger star is usually of a ruddy or orange hue, while the smaller one appears blue or green." † When the brighter star is yellow, the less bright one is usually blue: if the brighter be of a crimson hue, the smaller is of a greenish tint. This contrast of colours cannot be the effect of any optical delusion: for when one star is concealed from the eye, the other remains the same in colour that it was when both were viewed at once. Also, if it were the effect of such optical delusion, the phenomenon would be universal, which is by no means the case.

VARIABLE STARS.

Several stars have been observed to undergo a periodical variation in brightness. One remarkable law has been detected

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* Nichol's Architecture of the Heavens, p. 103, from which, and from a paper of M. Arago, in the Annuaire du Bureau des Longitudes for 1834, the principal facts in the latter part of this chapter are borrowed.

† *Herschel*, Astronomy, § 610.

in these variations, viz. that while the time elapsing between two successive epochs of greatest brightness is uniform for each star, the time which it takes to pass from its least light to its greatest is much shorter than the time in which it passes from its greatest light to its least. The rapidity with which the stars increase or decrease in brightness is by no means uniform, but subject to many perplexing irregularities. Thus Algol, or β Persei, during the greater part of its period of 2 days, and nearly 21 hours, remains unchanged, being then of a weak second magnitude. "When it begins to decrease, it sinks down in between three and four hours to the fourth magnitude, remaining in this state about a quarter of an hour; and then increases again to the second magnitude in between three and four hours, changing its brightness very rapidly as it passes through the third magnitude."* The periods of about eighteen stars have been accurately observed: the shortest is that of Algol, already stated; the longest, that of the star 30 Hydræ, is nearly 494 days.

Some stars seen in former years have disappeared from the heavens, while others, formerly invisible, have of late years made their appearance. Remarkable changes have also been observed to occur without, as far as can be ascertained, any periodical repetition. On November 9. 1572, a star, previously invisible, appeared with a brightness scarcely inferior to that of Venus. From the 11th of that month it gradually decreased, until in March, 1574, it disappeared, and has never since been seen. On October 10. 1604, a star, unseen the day before, burst forth with a brilliancy greater than that of Jupiter, and then gradually waned, and in October, 1605, no traces of it remained. These two stars seem to be of a peculiar kind; and no other similar instances have been observed.† On December 16. 1837, Sir John Herschel, then at the Cape of Good Hope, observed that the star η Argus, previously of the second magnitude, had suddenly become a star of the first magnitude, and was then almost equal to Rigel. It afterwards increased until it became the fourth star in the heavens in order of brightness. No satisfactory account has been given of the causes of any of the abovementioned variations.

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* Nichol, System of the World, p. 124.

† Halley, as quoted by Arago, Leçons d'Astronomie, Leçon 4.

In the course of time, the colours of some stars have undergone a change. Thus, Sirius, which in the time of the ancients was of a fiery red, is at present of a brilliantly white colour. (Nichol, Archit. of the Heavens, p. 104, note.)

ASTRAL SYSTEMS.

As the planets form parts of solar systems, so solar systems form parts of astral systems. The astral system to which we belong is an oblong ring, the outer parts of which are thickest strewn with stars, and constitute the milky-way, the apparent form of which was described in Chap. II. Our solar system lies near the inner edge of the southern portion of this ring. According to Professor Mädler, of Dorpat, the centre of the system lies in the Pleiades: the star η Tauri or Alcyone, probably occupies almost exactly the position of the centre of gravity of the system, and may, therefore, be called its central sun. Around this all the other stars of the system revolve, our sun among the rest. Alcyone is estimated to be 34,000,000 times as far from us as our own sun. Consequently its light occupies above five hundred years in travelling to us.

To our astral system belong all the heavenly bodies visible from the earth, with the exception of certain small cloud-like masses of light, called *nebulæ*, some few of which are discernible by the naked eye, but which are discerned in great numbers by the aid of telescopes. Very powerful telescopes discover many of these to consist of stars whose enormous distance blends them apparently into one mass. Hence it is inferred that they are all astral systems*, several of which are ascertained to be beyond all comparison larger than our own.

The distances of these *nebulæ* may be estimated by observing the magnifying power of the telescope which first begins to resolve them into their component stars. Some which have been thus examined are computed to be at so great a distance, that light takes upwards of thirty millions of years in travelling from them to us. In fact, in gazing on the heavens, we do not see the stars as they are, but as they were, some of them several years, some countless ages, ago: and possibly many stars, whose light is now reaching us, have themselves for a great length of time ceased to exist.

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* According to the theories of Sir W. Herschel and of Laplace, many nebulæ are systems in process of formation, and consist, some of luminous matter in a diffused state, some of matter partly diffused, partly condensed into distinct stars; the rest being systems which have passed through this process of formation, and consist entirely of distinct stars.

CHAPTER V.

Of the Solar System.

THE solar system consists of the sun, and those heavenly bodies which derive their light from the sun, viz., the earth, the moon, the planets, and their satellites, and comets.

The belief of the earliest astronomers was, that the stars were fixed in a crystal sphere, which revolved round the earth in the space of a day and a night. The irregular motions, however, of some of them required further explanation, which gave rise to several theories.

Thales of Miletus* (born B. C. 640.) is the first who is known to have taught the sphericity of the earth, which the earlier astronomers believed to be a circular plane surface. How much farther he advanced in the science of astronomy is doubtful: it is known, however, that he discovered the obliquity of the ecliptic, and could predict eclipses of the sun and moon.

Pythagoras (born at Samos, B. C. 590.) taught the diurnal and annual motions of the earth. His opinions, however, were never prevalent, and, though revived by Aristarchus of Samos†, in the third century before Christ, were entirely superseded by those of Hipparchus and Ptolemy.

Hipparchus, who lived in the second century B. C., taught that the earth was immoveable, and that the sun moved round it in a circular orbit; but, observing that the sun took 187 days to describe the northern half of the ecliptic, and only 178¼ to describe the southern half, he placed the centre of the circle, not in the earth, but at a distance from it equal to about one twenty-fourth part of the radius of the circle.

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* The principal facts of this historical sketch are borrowed from Laplace, Système du Monde, livre 5, and from the Hist. of Astronomy, in the L. U. K.

† Aristarchus was the first man of eminence in that series of astronomers called the Alexandrian school, which lasted from the accession of Ptolemy Lagus to the throne of Egypt till the conquest of Egypt by the Arabs. Hipparchus and Ptolemy also belonged to this school.

Claudius Ptolemæus (who lived about A. D. 130.) replaced this eccentric circle by an epicycle, that is, by a circle, whose centre revolved in a circular orbit round the earth as its centre. He supposed the rest of the heavenly bodies also to revolve round the earth in the following order; first, the Moon, then Mercury, Venus, the Sun, Mars, Jupiter, and Saturn; and lastly, the sphere containing the fixed stars. The various motions of the planets he explained by supposing them to move in epicycles, mounted upon other epicycles, in an ingenious but very complicated manner. The system of Ptolemy, further complicated by his successors, obtained universal belief until the time of Copernicus, who was born in Prussia A. D. 1473, and taught the system called by his name, which, with some modifications, is held at the present day.

Copernicus revived the Pythagorean theory of the immoveability of the sun, and taught that the earth and planets revolved round the sun, and the moon round the earth. He, however, believed their orbits to be epicycles, not, as since discovered, elliptical.

Tycho Brahe, a Dane (born A. D. 1546), revived the theory of the earth's immoveability, but differed from Ptolemy in teaching that the sun and moon revolved round the earth, while the rest of the planets revolved round the sun.

By the aid of a long series of astronomical observations, made by Tycho Brahe, Kepler, after the failure of many ingenious theories, succeeded in discovering the three great laws of our system, the truth of which has ever since been held; viz.,—

I. That the planets (including the earth) move in ellipses, each having one of its foci in the sun's centre.

II. That the areas swept out by each planet about the sun are, in the same orbit, proportional to the times of describing them.

III. That the squares of the periodic times of the planets about the sun are proportional to the cubes of the major axes of their orbits.

The truth of these laws was first demonstrated by Sir Isaac Newton, who showed that if the same laws of the motion and mutual attraction of matter* which are found to prevail in our earth, hold good for the sun and planets also, the planets cannot move in any other orbits. The Newtonian theory has been found to accord with the motions, not only of the moon and the then known planets, but of the planets and satellites since discovered, of those comets whose orbits have been calculated, and of all the multiple stars whose motions have been accurately observed. Hence it may be safely inferred that the same laws of attraction and motion prevail throughout our astral system, and probably through the whole universe.

The planets at present known are, Mercury, Venus, the Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. In addition to these there are between Mars and Jupiter eight small planets called *asteroïds*, viz., Vesta, Hebe, Astræa, Juno, Ceres, Pallas, Iris, and Flora. The Earth has one satellite; Jupiter, four; Saturn, seven; Uranus, probably, six; Neptune, at least one. Saturn and Neptune are surrounded by circular belts. All the planets move round the sun in the same direction, viz., from west to east.

In Plate V. a representation†, on a reduced scale, is given of the size of the sun as seen from the different planets. A notion of the relative magnitudes and distances of the parts of our system will, however, be best obtained from the following illustration‡:—"Choose any well-levelled field or bowling-green. On it place a globe two feet in diameter; this will represent the Sun; Mercury will be represented by a grain of mustard seed, on the circumference of a circle 164 feet in diameter for its orbit; Venus, a pea, on a circle 284 feet in diameter; the Earth, also a pea, on a circle of 430 feet; Mars, a rather large pin's head, on a circle of 654 feet; Juno, Ceres, Vesta, and Pallas, grains of sand, in orbits of from 1000 to 1200 feet; Jupiter, a moderate-sized orange, in a circle nearly half a mile across; Saturn, a small orange on a circle of four fifths of a mile; and Uranus, a full-sized cherry, or small plum, upon the circumference of a circle more than a mile and a half in diameter." Neptune will be represented by a good-sized plum on the circumference of a circle nearly two miles and a half in diameter.

That the planets and their satellites shine by the reflected light of the sun, is inferred from the fact that, while the sun's disc always appears of the same shape and size, the planets present to the eye a greater or smaller illuminated surface, according to their position relatively to the earth and sun.

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* These laws are given in the first part of this work.

† Borrowed from Nichol's Solar System.

‡ Given by Sir John Herschel, Astronomy, § 449.

THE SUN ⊙.

The apparent diameter of any heavenly body being observed by means of the micrometer, and its distance being also ascertained, its real diameter may easily be calculated. The sun is nearer to us in winter than in summer, and consequently appears larger in the former than in the latter season: its mean apparent diameter is calculated at 32′ 3″. Its mean distance from us is determined by observation of its parallax to be 95,000,000 miles. Its diameter is hence calculated to be 882,000 miles, that is, about 111½ times that of the earth; and since the volume of bodies is proportioned to the cubes of their diameters, its volume is to that of the earth in the proportion of 1,384,472 to 1. The density of the sun is found to be $\frac{26}{100}$, or little more than one-fourth part of that of the earth: its weight or mass, therefore, is to that of the earth as 354,936 to 1. Now, any two bodies which mutually attract each other revolve round their common centre of gravity, which is distant from each in inverse proportion to its mass. In this case we find that the common centre of gravity is at a distance from the sun's centre equal to 267 miles, or about $\frac{1}{3300}$ of its own diameter. The attraction of the other planets, acting in their various directions, lessens even this small distance. The sun may, therefore, for all practical purposes, be considered motionless.

By the observation of spots on the sun's surface, it is ascertained that it revolves in a direction from west to east, upon an axis inclined to the ecliptic at an angle of 82° 40′, completing one rotation in twenty-five days and about ten hours. Owing to this rotation, its figure, like those of the earth and other planets, is not strictly spherical, but somewhat flattened at the poles.

PHYSICAL CONSTITUTION OF THE SUN.

The sun is supposed to be an opaque and solid body, surrounded by two atmospheres; the inner one obscure, the outer luminous. This opinion is founded on the three following facts:—Firstly, on the sun's surface spots are observed, some luminous (called *faculæ*), others obscure. The latter are observed to be surrounded by a penumbra, which always appears broader on the side of the spot further from the spectator, while when the spot is directly opposite, it appears even all round. This evidently shows that the spots are pits in the sun's surface, as such an effect could not otherwise be produced. That the surface, thus broken, is of a gaseous nature is also evident; since, although the spots are sometimes as much as 50,000 miles in diameter, they open and close at a rate often surpassing a thousand miles a day — a rapidity of motion inconceivable in any but an aeriform body. The penumbra appears to be the edge of a dark inner atmosphere, the rent in which is narrower than that in the outer one. Secondly, the light of the sun possesses the properties of light derived from an incandescent gas; and is devoid of the properties belonging to light derived from an incandescent solid or liquid body. Thirdly, the light of the sun is as intense at its edges as at its centre; consequently the sun has no atmosphere exterior to the luminous one; for if this were the case, the light at the edges would be weaker than at the centre, having to pass through a greater thickness of exterior atmosphere.

There is, however, round the exterior atmosphere of the sun a very thin medium of an atmospheric nature, which probably extends, though not in equal density, through the whole solar system. This is inferred from the phenomenon called the *Zodiacal Light;* which consists of a faint luminous cone, observed after sunset about April or May, or before sunrise about October or November, to stream upwards from the horizon, following the course of the sun's equator, and extending beyond the orbits of Mercury and Venus. The distance of its base from its vertex varies from 40° to 90°; the breadth of its base, measured perpendicularly to its axis, from 8° to 30°. It is very faint in this climate, but better defined in tropical regions. That this medium reaches beyond the extent to which it is visible is inferred from the fact that irregularities occur in the motions of comets, which cannot be accounted for but by the supposition of a retarding medium.

MERCURY ☿.

Mercury is the nearest planet to the sun, and the smallest, with the exception of the asteroïds. He appears in the evening after sunset in the western part of the heavens, and gradually increases his distance from the sun. After a certain limit he appears stationary, and then returns to the sun, and finally disappears within its rays. He soon after reappears before sunrise, and rises earlier every day, until at a certain distance from the sun he again becomes stationary, and shortly afterwards retraces his path towards the sun. His greatest distance, or elongation from the sun, varies from 16° to 28° 48′.

Mercury in fact appears to a spectator from the earth to move backwards and forwards in a path varying considerably in length, and slightly in direction, at either end of which he remains for a short time stationary. His apparent diameter is found, on examination by the micrometer, to undergo continual variations, which can be produced only by variations in his distance from us. By a comparison of these with his apparent path, his real path is ascertained to be an ellipse of smaller dimensions than the earth's orbit, and inclined to it at a certain angle. The *ascending node* of Mercury, that is, the point from which he ascends northward above the ecliptic, is in the fifteenth degree of Taurus; his *descending node*, in the fifteenth degree of Scorpius.* If Mercury comes to either of his nodes at his inferior conjunction, (that is, when he is between the earth and the sun,) he will pass over the sun's disc, and appear upon it as a black spot. This can only occur about May 6th or November 7th, at which times the sun is respectively in the fifteenth degree of Scorpius and the fifteenth degree of Taurus. This phenomenon is called the *transit* of Mercury, and recurs regularly after periods of 6, 7, 13, and 263 years.

The apparent movements and phases of Mercury, as well as of the other inferior planet, Venus, may be understood from Plate IV. Fig. 8. S represents the sun; T, E, e, various positions of the earth; *x*, *v*, *w*, *a*, *h*, *g*, *f*, of Mercury or Venus. The positions T and *a* represent the inferior conjunction, at which time the planet disappears like the new moon, its dark side being turned towards the earth. As it moves from *a* to *w*, it gradually shows a larger enlightened surface, until at *v* the position of greatest elongation (*i. e.* the position at which its apparent distance from the sun subtends the greatest angle), it appears half enlightened, like the moon in her first quarter. As it advances, it shows a larger enlightened surface, until at last it is hidden by the sun's rays. It soon after emerges, and from that time shows a continually decreasing illuminated surface, until it again disappears at *a*. As it moves from its inferior to its superior conjunction along the orbit *a w v x*, it rises before the sun, and is called a morning star; as it moves through the other half of its orbit, it sets after the sun, and is called an evening star.

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* The nodes of all the planets have a retrograde motion, in no case exceeding a degree, in few half a degree, in a century.

From its greatest elongation when west of the sun, as at *v*, to its greatest elongation east of the sun, as at *g*, it will appear to advance, describing among the fixed stars the orbit V W H G; from *g* to *v* it will have an apparently retrograde motion, returning in the direction G H W V. Near *g* and *v*, its motion, being nearly in a straight line towards or from the earth, is distinguishable only by the variations in the planet's apparent size. Hence, when at or near those points it is said to be stationary.

Did the earth stand still during the revolution of the planet, they would be again in conjunction after one entire revolution of the planet in its orbit; but, since, while the planet has been moving through the orbit *avxa*, the earth has also been moving in the direction of E, they will not be again in conjunction, until the planet is more or less advanced in a new revolution. Hence the *sidereal period* of an inferior planet is less than the *synodical period*, or interval between two successive conjunctions; and for the same reason the sidereal period of the earth is somewhat less than the synodical period of a superior planet. Hence, also, no two successive points of conjunction or opposition are the same in position.

Mercury revolves round the sun in an orbit inclined to the ecliptic at an angle of 7°, and having a mean radius of 37 millions of miles. He completes his sidereal period in about three-quarters of an hour less than 88 days, moving in his orbit at a mean rate of 30 miles per second. His synodical period is a little less than 116 days. The great variation observed in his angle of greatest elongation is attributable to the great eccentricity of his orbit, which is about $\frac{1}{5}$ of its mean radius. He revolves on his axis in $24^h\ 5'\ 3''$. The inclination of his axis to the plane of his orbit is unknown.

The elements of the earth being taken as units, Mercury's distance from the sun is ·387; his diameter, ·39; his volume,

·06; his density, 2·95; his mass, ·17; the proportion of light and heat received by him from the sun, 6·6.

Owing to the small size of Mercury, and his nearness to the sun, nothing has been ascertained with certainty of his physical constitution.

VENUS ♀.

Venus is the brightest and most beautiful of all the stars. Her motions and phases are similar to those of Mercury. Her angle of greatest elongation is nearly uniform, varying from 45° to 47°. She was known to the ancients as a morning star by the names of Phosphorus or Lucifer (Light-bringer); as an evening star by the names of Hesperus or Vesper.

Her orbit, which is nearly circular, is inclined to the ecliptic at an angle of 3° $23\frac{1}{2}'$, and has a mean radius of 69 millions of miles, or about $\frac{3}{4}$ of that of the earth. She consequently receives about twice as much light and heat from the sun. She completes her sidereal period in $224^d\ 16^h\ 49'$, travelling in her orbit at the rate of 22 miles per second. Her synodical period is about 584^d. She performs a rotation in $23^h\ 21'\ 19''$ on an axis inclined to the plane of her orbit at an angle of 15°. In size, she differs little from the earth, being 7800 miles in diameter: hence her volume is calculated to be about ·91 of that of the earth. Her density is about ·01 less than that of the earth: consequently her mass is about ·89 of the earth's mass.

The transits of Venus take place alternately, at intervals of about 8 and 113 years: the last was in 1769. The two next will take place on December 8. 1874, and December 6. 1882. The longitude of her ascending node, at the commencement of the present century, was about 74° $54\frac{1}{4}'$.

PHYSICAL CONSTITUTION OF VENUS.

Venus has a very large atmosphere*, and consequently a long dawn and twilight. Owing to the magnitude of this atmosphere, which is required to mitigate the intensity of the sun's heat, the irregularities on her surface are scarcely discernible, and she presents to the telescope the appearance of an even bright silver disc. Upon the edge of her crescent, however, irregularities are perceived, presenting the appearance of huge mountain chains, probably of greater magnitude than any on our globe. Owing to the small inclination of the axis of Venus to her orbit, her seasons and her days and nights vary in length far more than our own, and her inhabitants are exposed to much greater extremes of heat and cold. For the same reason, the portion of her surface over which the sun rises and sets daily throughout the year occupies but a small zone about her equator, not, as is the case with our earth, the larger portion of the sphere.

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* The usual method of discovering the extent of the atmosphere surrounding any heavenly body consists in a careful observation of the occultations of the fixed stars by that body. The refraction of the atmosphere of the body, if any exists, will have the effect of retarding the commencement of the occultation, and accelerating its conclusion, just as the refraction of our own atmosphere retards the apparent setting of the sun while it accelerates its apparent rising.

No satellites have as yet been discovered, attending either upon Mercury or Venus.

THE EARTH ⊕.

The figure and magnitude of the earth have been explained in Part I. Ch. III.; its diurnal and annual revolutions, distance from the sun, seasons, &c. in Part I. Ch. IV.

THE MOON ☽.

By a series of observations of the moon's apparent angular motion, and of the variation in her distance as shown by the variation in her apparent size, her apparent path in the heavens is discovered to be elliptical. That the moon moves round the earth, not the earth round the moon, is evident for two reasons: firstly, because it has been shown that the earth moves round the sun, and it is impossible for a body to move round two fixed centres at once; secondly, because her mass is much smaller than that of the earth; and it is contrary to the observed laws of motion that a smaller body should move round a larger. The moon then moves round the earth in an elliptical orbit. The inclination of this orbit to the ecliptic varies from 5° to 5° 18′. Its mean inclination is 5° 8′ 48″. Its mean radius is about 237,000 miles, or nearly sixty times the equatorial radius of the earth. Its mean eccentricity is nearly ·055 of the mean radius.

Did the sun exercise no attractive influence on the moon, her orbit would, as referred to the earth, be an ellipse of invariable form and magnitude. The sun's attraction, however, sensibly affects the eccentricity of her orbit, and produces most perplexing irregularities in her motion. When the moon is in or near conjunction, that is, between the earth and the sun, the sun's attraction tends to draw her away from the earth, and consequently to increase her distance: when the moon is in or near opposition, the sun acting more strongly on the earth, as being nearer to it, tends to draw it away from the moon, and thus again to increase the distance between them. At or near the quadratures, the sun's attraction acts more equally on both; hence the earth's attraction acts more uninterruptedly on the moon, and the distance between them is lessened. Hence the sun's attraction tends to elongate the moon's orbit in the direction of the points of conjunction and opposition, and to flatten it in the region of the quadratures. Now, any cause which lengthens the major, or shortens the minor, axis of an ellipse, increases its eccentricity, and *vice versa.* Hence, when the major axis or line of apsides is in the syzygies, the eccentricity of the moon's orbit is greatest; when the major axis is in the quadratures, the eccentricity is least. These irregularities in the moon's orbit are called *evections.*

Hence, by Kepler's second law, the sun's attraction must tend to diminish the moon's velocity as she approaches the points of conjunction and opposition, and to increase it as she approaches the quadratures. The moon's velocity and the eccentricity of her orbit will not, however, vary uniformly every revolution, inasmuch as the sun is nearer to the earth and moon at some parts of the year than at others, and consequently exercises a greater disturbing influence. Hence both eccentricity and velocity are subject, within certain limits, to almost infinite variations.

The moon completes a sidereal revolution round the earth in a mean period of $27^d\ 7^h\ 43^m\ 11''{\cdot}5$. As, however, the sun has, in the meantime, made an apparent advance in the same direction, she must perform rather more than one sidereal revolution in passing from one conjunction to another. Accordingly, her synodical period is somewhat longer than her sidereal period, having a mean length of $29^d\ 12^h\ 44^m\ 2''{\cdot}87$.

It is found, by observation, that the moon cuts the ecliptic every revolution at a point a little west of that at which she cut it the previous revolution. Her apparent path in the heavens is consequently not an exact ellipse, but rather an elliptical spiral. This retrogradation of the moon's nodes on the ecliptic is found to proceed at a mean daily rate of about $3'\ 10''\cdot64$. Hence the ascending node is carried round the ecliptic in a direction contrary to the moon's orbit in a period of 6793·39 solar days, or about 18·6 years. After the completion of this period she recommences the same apparent path as before. On account of this retrogradation of the nodes, the moon's *nodical period*, or time of passing from one ascending node to another, is somewhat shorter than her sidereal period, having a mean length of $27^{d}\ 5^{h}\ 5^{m}\ 35''\cdot6$.

Were the transverse axis, or line of apsides, of the moon's orbit always parallel to itself, the interval between perigee and perigee would be identical with her sidereal period; its axis, however, has a continual angular movement in the same direction with the moon's motion. Hence, since the position of the moon's perigee advances during her revolution in her orbit, she has to perform rather more than an entire sidereal revolution before coming to it again. Hence the time occupied in passing from perigee to perigee, or from apogee to apogee, termed the *anomalistic period**, is longer than the sidereal period, having a mean length of $27^{d}\ 13^{h}\ 43^{m}\ 11''\cdot51$. An entire revolution of the moon's apsides is completed in $3232\frac{1}{2}^{d}$, or about nine years.

The phases of the moon, and the eclipses of the sun and moon, will be discussed in the succeeding chapter.

The moon rotates in a direction contrary to that of her orbital motion, on an axis inclined to her orbit, at an angle of 84° 51′ 11″. She completes a rotation in $29^{d}\ 12^{h}\ 44^{m}\ 2''\cdot87$, that is, in exactly the same time that she takes to complete one revolution round the earth. Hence she always presents to the earth precisely the same face, or rather would do so, did she not, from other causes, show a little more sometimes of one side of this face, sometimes of another. These changes, having the appearance of the swaying motion of a balance, are termed *librations*. They are of four kinds, arising from four distinct causes.

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* So called because the angular distance from apogee is termed the *true anomaly*. The sun's apsides alter their position by but $11''\cdot8$ yearly; hence the anomalistic year, which is longer than the sidereal year by the time taken by the sun in describing this arc, exceeds it only by $4^{m}\ 47''\cdot3$. A revolution of the sun's apsides is completed in about $109{,}830\frac{1}{2}$ years.

1. The moon's motion in her orbit varies according to her distance from the earth, while her motion of rotation is uniform. Hence, when her motion in her orbit is quicker than her mean motion, she shows somewhat more than usual of the eastern, somewhat less of the western side of her face; when slower, somewhat more of the western, and less of the eastern. Distance east and west on the moon's equator is measured by *lunar longitude;* hence this phenomenon is termed the moon's *libration in longitude*.

2. Were the moon's axis perpendicular to her orbit, she would always show us equal portions north and south of her equator. But since it is inclined to it at an oblique angle, and but slowly changes its parallelism to itself, its poles are in turn directed towards the earth. Hence, at one part of her revolution, the surface about her north pole is visible from the earth; at another, the surface about her south pole; while, when the moon's axis is perpendicular to the line joining the centres of the earth and moon, equal portions of her northern and southern hemispheres are visible. This is her *libration in latitude*.

3. In the preceding paragraph the spectator is supposed to be situate on a line joining the centres of the earth and moon. This, however, is the case only when the moon is in the zenith. Now, the part of the moon presented to any observer is bounded by a circle perpendicular to a line joining the observer's position with the moon's centre. Hence, since the moon is not so distant but that lines joining her centre with different positions on the earth's surface may make a sensible angle*, it follows that sensibly different portions of the moon may be presented at the same time to observers on different spots on the earth's surface. Hence the visible portion of the moon's surface will be sensibly, though but slightly, different, according to her position in the observer's visible hemisphere; that is, to her altitude and azimuth. This phenomenon is termed the moon's *diurnal or parallactic libration*.

4. The above appearances of libration arise from optical

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* This angle is evidently greatest when the two spots on the earth's surface are on opposite sides of the horizon. Its mean value in this case is about 2°.

causes. The moon has, however, a real libration; its axis of rotation, which for one revolution is almost precisely parallel to itself, being found not to preserve its parallelism for any length of time. It was formerly believed that it was perpendicular to the ecliptic, and, consequently, that the moon's equator was parallel to the ecliptic. Cassini discovered that the moon's equator is inclined to the ecliptic at an angle of 1° 28′ 25″, and that, if through the moon's centre planes be drawn parallel to the ecliptic and the moon's orbit, these planes will cut the moon's equator in the same straight line, viz., in the line of the nodes. Hence the moon's axis of rotation and her orbital axis are always perpendicular to the line of the nodes. Hence, being inclined to the axis of the ecliptic at constant angles, they will, in the course of a revolution of the nodes, mark out with their poles small circles round the pole of the ecliptic; and since the three planes intersect in the same straight line, their poles will always lie in the same great circle of the heavens. This motion of the moon's axis of rotation produces a vibratory motion of the moon, the period of which is 18·6^{y}, being completed in one revolution of the nodes. Such vibration is a necessary effect of attraction acting on a body of the moon's spheroidal form: it is hence called the moon's *spheroidal libration*. To an observer situate in the moon, the earth would present the appearance of a moon nearly 2° in diameter, immovably fixed in the sky, or at least having only the slight motion caused by libration.

The earth's dimensions being taken as units, the moon's diameter will be ·27; her surface, ·07; her volume nearly ·02; her density, ·76; her mass, ·015.

PHYSICAL CONSTITUTION OF THE MOON.

In Plate VII. a representation is given of that hemisphere of the moon which is presented towards the earth. Many spots on its surface are marked as seas. They were so named by the older astronomers, who believed them to be seas. The names are still retained for the purpose of recognition; but as no lunar atmosphere has been detected, and as the absence of an atmosphere involves the absence of every kind of liquid*, the so-called seas are now believed to be extensive plains. This is further proved by the fact that they are found to be marked with slight irregularities of surface. Great irregularities are observed on the moon's disc, which from the shadows cast by them, and from their jagged appearance, when seen on the moon's edge, are evidently mountains. The height of some has been computed from the length of their shadows. The perpendicular altitude of the highest is found to be about 1¾ statute miles. The lunar mountains are very numerous, covering, with their irregularities, two-thirds of the moon's disc. They are mostly of a cup-shaped form, enclosing flat surfaces, from the centre of each of which rises a small steep conical hill. The diameters of these craters or cups vary from the smallest visible size (about 500 feet), to 50 or 60 miles. The inner side of the enclosing ridge is much steeper than the outer, and is often divided into concentric ridges, in the form of terraces. The lunar mountains are essentially of a volcanic character.

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* Without the pressure of an atmosphere, liquid will expand and assume an aeriform shape, thus making an atmosphere for itself.

The moon's axis of rotation being nearly perpendicular to the ecliptic, the sun never sensibly departs from its equator; hence it enjoys no change of seasons. Its nights are of the length of nearly fifteen of our days, during which time one of its hemispheres never enjoys the light of a satellite. Having no appreciable atmosphere, the moon has no twilight; the transition from light to darkness, and the contrary, being momentary. From its want of air and water, the moon cannot possess inhabitants whose organisation is similar in any respect to any animals found upon our globe.

MARS ♂.

Mars is the nearest of the superior planets, or those whose distance from the sun is greater than that of the earth. That their orbits enclose that of the earth is shown from their not being confined within certain limits of elongation from the sun, but being seen at all distances from it; and, further, from their phases always appearing more than half full. The enlightened portion of Mars is never less than seven-eighths of its hemisphere, while Jupiter and the more distant planets always appear round. This is a proof that we always see them nearly in the direction in which they are illuminated by the sun's rays; from which it follows that the earth's distance from the sun is very small compared with that of the planets above-mentioned.

The apparent motions of the superior planets are alternately direct and retrograde; in the intervals between these motions they appear for a time stationary. In *Plate* IV. *Fig.* 8. let S be the sun; M one position of Mars, or any superior planet; the circle on which M is placed, its orbit; TE*te*, the earth's orbit. When the earth is at T, the sun and planet are said to be in conjunction; when at *t*, in opposition. Let us suppose the planet to remain stationary at M. Then, as the earth moves from T to E, the planet will appear to have a direct motion in the heavens, viz. from P to *m*. At E the line joining the earth and the planet nearly coincides for some little distance with the earth's orbit; hence, for a short time, the line of view in which the planet is seen will remain nearly the same, and the planet will appear stationary. As the earth moves from E through *t*, the point of opposition, to *e*, the planet will have in the heavens an apparently retrograde motion, viz. from *m* to *n*. When the earth is at *e*, it will again appear stationary; and as the earth moves from *e* to T, the point of conjunction, the planet will again have an apparently direct motion towards P. It appears, then, that the planet must have an apparently direct motion as it passes through the point of conjunction, an apparently retrograde motion as it passes through that of opposition; while, when the line joining the earth and the planet is a tangent to the earth's orbit, it will appear stationary.

Let now the planet have a motion in the direction MO, *i. e.* in the direction of the earth's motion. The effect will be to lengthen each period of direct and retrograde motion and of opposition. For, if while the earth moves from T to E, the planet moves from M to O, the line joining the two bodies will not be a tangent to the earth's orbit until the earth has made a further advance. Hence, the period of direct motion is lengthened. If the planet appears stationary when the bodies are at E and M, and while E moves a little towards *e*, M moves a little towards O, the line EM will preserve the same direction for a longer time, and the length of the stationary period will be increased. If when the earth has arrived at *e*, the planet has advanced to O, the line joining them will not be a tangent until the earth has advanced to *s*; hence the retrograde period will be lengthened. It is, of course, supposed that the angular motion of the planet round the sun is, like that of all the exterior planets, less rapid than the earth's angular motion; so that at certain intervals the earth overtakes the planet, not the planet the earth.

While the earth moves through a whole revolution, the planet moves through a part of its orbit; hence between two points of opposition or conjunction the planet will have made an apparent advance in the heavens. This advance is greater, the more rapid the planet's angular motion, that is, the smaller its orbit. Hence the synodic time or period between two conjunctions or oppositions is longer for planets nearer the earth. It will also be seen from the figure, that the nearer the planet M is to the earth's orbit, the greater is the extent of the arcs of direct and retrograde motion; the longer the duration of each motion, the greater its rapidity when swiftest.

It is further evident from the figure, that the planet's apparent motion is swiftest when near the points of opposition or conjunction; slowest, when near the stationary points.

The mean distance of Mars from the sun is 146,000,000 miles. His orbit is inclined to the ecliptic at an angle of 1° 51′ 6″. Its eccentricity is very great, being ·093, or nearly $\frac{1}{10}$ of its mean radius. He moves in his orbit at a mean velocity of fifteen miles per second, and completes his sidereal period in $686^d\ 23^h\ 31'\ 22''$, or about six weeks less than two years. His synodical period is about 780^d, or $2^y\ 50^d$.*

The diameter of Mars is about 4100 miles. His equatorial is to his polar diameter in the proportion of 16 to 15. He has a rotation on an axis inclined to the plane of his orbit at an angle of about 61° 33′, in a period of $24^h\ 39^m\ 21''$, and in the same direction as the earth's rotation.

The earth's elements being taken as units, the distance of

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* "The following very simple algebraical formula determines the synodic times in terms of the periodic times. Let A and B be the periodic times of any two planets in days, then are $\frac{360}{A}$ and $\frac{360}{B}$ their mean daily motions, and $\frac{360}{A} - \frac{360}{B}$ is their relative daily motion. Let S be their synodic time in days, or the number of days in which they separate from one another in longitude through 360°; then $\frac{360}{S}$ is their daily separation or relative motion.

"Therefore, $\frac{360}{S} = \frac{360}{A} - \frac{360}{B}$; $\frac{1}{S} = \frac{1}{A} - \frac{1}{B}$; and $S = \frac{AB}{A-B}$."—*Moseley's Lect. on Astr.* § 62.

Mars from the sun is about 1·5; the light and heat received by him, ·44; his diameter, ·56; his volume, ·17; his density, ·79; his mass, ·14.

PHYSICAL CONSTITUTION OF MARS.

Mars is, like the earth, enveloped in an atmosphere, which is, however, so clear that we can discern very distinctly on his surface the outlines of what appear to be continents and seas. "The former are distinguished by that ruddy colour which characterises the light of this planet, (which always appears red and fiery), and indicate, no doubt, an ochrey tinge in the general soil, like what the red sandstone districts on the earth may possibly offer to the inhabitants of Mars, only more decided. Contrasted with this (by a general law in optics), the seas, as we may call them, appear greenish."* (See *Plate* V. *Fig.* 1., which is a representation of Mars by Sir John Herschel, as seen in its gibbous state.) Bright white spots are observed about each pole; the spot about the north pole appears in *Fig.* 1., while that about the south pole is shown in *Fig.* 2., which is a representation by Mädler of Dorpat of the southern hemisphere. It is observed that as each pole is turned towards the sun, the brightness around it gradually contracts. Hence these white spots are conjectured to be the arctic and antarctic snows of Mars.

This inclination of the axis of Mars to his orbit does not greatly differ from that of the earth to the ecliptic. Hence his seasons, and the length of his days and nights, vary in very nearly the same proportions as our own.

THE TELESCOPIC PLANETS OR ASTEROIDS.

In the year 1772, Professor Bode, of Berlin, observed the following law in the distances of the planets from the sun. The mean distance of Saturn from the sun being taken as 100, the mean distances of the planets are, —

Mercury		4
Venus	4+3=	7
The earth	4+2.3=	10
Mars	4+2.2.3=	16
* * * *	*	*
Jupiter	4+2.2.2.2.3=	52
Saturn	4+2.2.2.2.2.3=	100

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* Herschel, Astronomy, § 437.

Uranus and Neptune, since discovered, have been found to conform to the same law. There being a deficiency of a term between Mars and Jupiter, several astronomers conjectured the existence of some planet, which from its small size had escaped notice. Such a planet was discovered by M. Piazzi, astronomer royal at Palermo, on January 1st, 1801, and named by him Ceres ⚳. Other small planets have since been discovered at nearly the same distances from the sun as Ceres; viz., Pallas ⚴, by Dr. Olbers, of Bremen, March 28th, 1802; Juno ⚵, by M. Harding of Lilienthal, Sept. 2nd, 1804; Vesta ⚶, by Dr. Olbers, March 29th, 1807; Astræa, by M. Henke of Driessen, December 8th, 1845; Hebe, by the same, July 1st, 1847; Iris, August 13th, and Flora, October 18th, in the same year, by Mr. Hind of Cambridge, at London.

These bodies are also called the *ultra-zodiacal* planets, from the curious fact that while the orbits of all the other planets lie within the zodiac, and are none of them inclined to the ecliptic at a greater angle than 6°, the inclination of the orbits of the asteroids varies from 5° 20′, the inclination of Astræa, to 34° 34′ 55″, the inclination of Pallas.* That of Vesta is 7° 8′ 9″; of Ceres, 10° 37′ 26″; of Juno, 13° 4′ 9″; of Hebe, about 15° 3′.

Their respective mean distances from the sun, in millions of miles and radii of the earth's orbit, are, Vesta, 225 or 2·37; the new planet, 240 or 2·5; Astræa, 247 or 2·6; Juno, 253 or 2·67; Ceres and Pallas are at nearly the same distance, that of the former being 262,903,570 miles, or 2·767 radii of the earth's orbit; that of the latter, 262,921,240 miles, or 2·773 earth's radii.

Their periods are,—Vesta, 1325·7^{d}; the new planet, 1461·5^{d}; Astræa, 1524^{d}; Juno, 1592·7^{d}; Ceres, 1681·4^{d}; Pallas, 1686·5^{d}.

These planets are of so small dimensions that astronomers have as yet been unable accurately to measure their diameters. The earth's diameter being unity, that of Vesta is estimated at about ·034; that of Juno at ·17; that of Ceres at ·05; that of Pallas at ·01. These, however, are mere conjectures. Vesta has no appreciable atmosphere; Juno and Ceres very extensive atmospheres; and Pallas an atmosphere supposed to be of a height equal to twelve times its radius.

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* The elements of Iris and Hebe have not yet been accurately calculated.

From the great angles made by these planets with the ecliptic, they have by some been thought to be the fragments of a large planet. This is further rendered probable by the two following remarkable facts; firstly, their faces are not round like those of the other planets; secondly, their orbits intersect in the same point, and it can be proved by the laws of mechanics, that were a planet to burst, its fragments would describe new orbits, intersecting in the point at which the explosion took place.

JUPITER ♃.

Jupiter is the largest of the planets, being no less than 87,000 miles in diameter. He revolves in an orbit inclined to the ecliptic at an angle of 1° 18′ 51″, and having a mean radius of about 494,500,000 miles. Its eccentricity is moderate, being ·048, or nearly $\frac{1}{20}$ of its mean radius. He completes his sidereal period in about $11^y\ 315^d$, travelling in his orbit at a mean rate of 8 miles per second. His synodical period is about $1^y\ 33^d\ 21^h$.

Jupiter revolves in $9^h\ 55^m\ 50^s$, on an axis inclined to the plane of his orbit at an angle of about 86° 55′, that is, nearly perpendicular to it. Owing to his rapid rotatory motion, he is much flattened at the poles, his equatorial and polar diameters being in the proportion of 107 to 100.

The elements of the earth being taken as units, Jupiter's distance from the sun is 5·2; his diameter, 11·56; his volume 1470; his density, ·23; his mass, 339·3; the light and heat received by him from the sun, ·036.

JUPITER'S SATELLITES.

Jupiter is attended by four satellites or moons, which, like our moon, revolve on their axes once during each revolution in their orbits, and consequently always turn the same face towards him. Their orbits are inclined at very small angles to that of Jupiter: their periods are, respectively, about $1^d\ 18\frac{1}{2}^h$, $3^d\ 13\frac{1}{4}^h$, $7^d\ 3\frac{3}{4}^h$, and $16^d\ 16\frac{1}{2}^h$: their mean distances about 6, $9\frac{1}{2}$, $15\frac{1}{3}$, and 27, of Jupiter's radii. They revolve round him in the same direction in which the moon revolves round the earth, and, like all other satellites, follow the same laws of motion round the primary planet, that the planets do round the sun. They are invisible to the naked eye, and were the earliest discoveries made by Galileo, the inventor of the telescope.

Their eclipses and occultations are of great use in the discovery of the longitude of any place.

It was observed by Römer, a Dane, who was born in 1644, that the eclipses of Jupiter's satellites are seen when the sun and Jupiter are in opposition, $8\frac{1}{4}^{m}$ earlier than the time predicted by calculation; when the sun and Jupiter are in conjunction, $8\frac{1}{4}^{m}$ later. Hence he concluded that the motion of light, instead of being, as before thought, instantaneous, must take $16\frac{1}{2}^{m}$ in traversing a space equal to the diameter of the earth's orbit.

PHYSICAL CONSTITUTION OF JUPITER.

A representation of Jupiter is given in *Plate* V. *Fig.* 3. The dark belts there delineated are not alike at all times. They vary in breadth and situation, though not in their general direction, which is parallel to the equator. They sometimes remain the same for three months, sometimes change their form in the course of an hour or two. They have very rarely been seen broken up and distributed over the whole disc. From these circumstances it is inferred that the belts are of an atmospheric character. They are thought to be tracts of comparatively clear sky, caused by currents analogous to our trade winds, though more steady and decided. That such would be the case might be expected from the great size of Jupiter, and its rapid rotation, from the combination of which causes a body on the surface of its equator travels at nearly twenty-eight times the speed of a body on the surface of the earth's equator. In these and other respects the winds and atmospheres of Jupiter resemble our own. Hence it appears probable that his surface is divided into land and water, like that of our earth, and of Mars. His axis being nearly perpendicular to his orbit, he experiences no sensible change of season in his progress round the sun.

SATURN ♄.

Saturn revolves in an orbit inclined to the ecliptic at an angle of 2° 29′ 35″, and having a mean radius of 915,000,000 miles. Its eccentricity is rather larger than that of Jupiter's orbit, being about ·056 of the mean radius. He completes his sidereal period in about $29\frac{1}{2}^{y}$, travelling in his orbit at a mean rate of six miles per second. His synodical period is about $378^{d}\ 2^{h}$.

Saturn revolves in 10^h 16^m on an axis inclined to the plane of his orbit at an angle of about 60°. His equatorial is to his polar diameter in the proportion of 11 to 10.

The elements of the earth being taken as units, Saturn's distance from the sun is about 9·54; his diameter, 9·61; his volume, 887·3; his density, ·11; his mass, 101·1; the light and heat he receives from the sun, ·011.

SATURN'S SATELLITES.

Saturn has seven satellites, at mean distances in terms of his radii of about 3, 4, 5, 7, $9\frac{1}{2}$, 22, and 64, and revolving round him in periods of about $22\frac{1}{2}^h$, 1^d 9^h, 1^d $21\frac{1}{4}^h$, 2^d $17\frac{3}{4}^h$, 4^d $12\frac{1}{2}^h$, 15^d $22\frac{3}{4}^h$, and 79^d 8^h. The six interior planets move in nearly circular orbits, whose planes nearly coincide with that of Saturn's equator. The seventh more nearly coincides with the ecliptic.

Saturn's sixth satellite was discovered by Huygens, a Dutchman, in the year 1655; his third, fourth, fifth, and seventh, by Cassini, between the years 1671 and 1685; his first and second by Sir W. Herschel, in the years 1787 and 1789.

SATURN'S RING.

Saturn is distinguished from all the planets, except, perhaps, Neptune, by the possession of a thin broad concentric ring, lying in the plane of his equator. This ring, upon examination by a powerful telescope, is found to separate into five, some say seven, belts, lying one within the other in the plane of his equator. The largest interval between the rings is represented in *Plate* V. *Fig.* 4., and is about 1800 miles in breadth. The breadth of the other divisions varies from about one to three hundred. The space between the ring and Saturn is 19,000 miles; the whole breadth, 27,000; the thickness not above 100 miles. The rings revolve round Saturn in periods proportionate to their distances; the period of the outermost ring is about $10\frac{1}{2}^h$.

PHYSICAL CONSTITUTION OF SATURN.

Saturn is, as represented in the figure, marked by dark belts like those of Jupiter, but broader and less strongly marked. Their cause is evidently the same as that of the belts of Jupiter. Saturn must, therefore, be possessed of an atmosphere. The ring is an opaque substance, as is known from its throwing a dark shadow on the planet. It conceals the light of the sun from those situated on the planet's equator for eighteen of our years at a time; during the rest of the planet's revolution, and at all times to those not situate exactly under it, it appears like a luminous arch in the heavens. The inclination of Saturn's equator to the plane of his orbit being about 6½° less than that of the earth, his seasons and the length of his days and nights vary a little more than our own. He appears, as seen from the earth, of a pale leaden colour.

URANUS ♅.

Uranus was discovered by Sir W. Herschel on March 13th, 1781. It was by its discoverer called the Georgium Sidus, or Georgian, in honour of George III., by which name it is still known in the Nautical Almanac. It is now, however, almost universally called Uranus, Uranus being in the Greek mythology the father of Saturn, as Saturn is the father of Jupiter, and Jupiter of Mars.

Uranus revolves round the sun in an orbit inclined to the ecliptic at an angle of $46' 28''\cdot4$, and having a mean radius of about 1800 millions of miles. Its eccentricity is nearly the same as that of Jupiter, being about ·047 of its mean radius. He completes his sidereal period in rather more than eighty-four years, travelling in his orbit at the rate of four miles per second. His synodical period is about 369^{d} $15\frac{3}{4}^{h}$.

The time of the diurnal rotation of Uranus is unknown. His axis of rotation is thought to be inclined to the plane of his orbit at an angle of about 11°.

The elements of the earth being taken as units*, the distance of Uranus from the sun is 19·18; his diameter, 4·26; his volume, 77·3; his density, ·26; his mass, 19·81; the light and heat received by him from the sun, ·0027.

URANUS'S SATELLITES.

Sir W. Herschel, the discoverer of Uranus, imagined that he discovered six satellites, at respective distances, in terms of the planet's radius, of about 13, 17, 20, 22¾, 45½, and 91. Their sidereal periods he fixed respectively at about $5^d\,21\frac{1}{2}^h$, $8^d\,17^h$, $10^d\,23^h$, $13^d\,11^h$, $38^d\,1\frac{3}{4}^h$, and $107^d\,16\frac{3}{4}^h$. The second and fourth only have been observed by other astronomers. These satellites possess two remarkable peculiarities; their orbits are inclined to that of the planet at angles of about 78°, and their motion is retrograde, whereas the motions of the satellites of the earth, Jupiter and Saturn, are direct.

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* Most of these comparisons of the elements of the various planets with those of the earth are borrowed from Plisson, Les Mondes, Paris, 1847.

PHYSICAL CONSTITUTION OF URANUS.

Nothing is yet known with respect to the existence of an atmosphere around Uranus. All the other primary planets, however, being possessed of them, it would appear probable that Uranus is so also. Owing to the inclination of his axis, the variation in the temperature of his seasons, and in the length of his days and nights, must be very great.

NEPTUNE. ♆

Neptune, the most remote planet at present known, was first observed by Dr. Galle, of Berlin, September 23rd, 1846. For several years irregularities had been observed in the motions of Uranus, which M. Le Verrier, in June, 1846, pronounced to be caused by the disturbing force of some exterior planet. On August 31st, in the same year, he gave the planet's distance from the sun, the form and position of its orbit, its place in the heavens, and its apparent magnitude, with such accuracy that it was at once discovered by Dr. Galle. It was afterwards found that Mr. John Couch Adams, of St. John's College, Cambridge, had previously calculated the planet's elements, and had arrived at nearly the same results, which he had communicated in October, 1845, to the Astronomer Royal of England.

Neptune revolves round the sun in an orbit inclined to the ecliptic at an angle of $1^\circ\,47'\,1''{\cdot}5$, and having a mean radius of about 2,870,000,000 miles. Its eccentricity is about ·008 of the mean distance. Neptune completes his sidereal period in a little less than 166 sidereal years, moving at a mean rate of about 3 miles per second. His synodical period is about 367 days.

The time of the diurnal rotation of Neptune, and the angle of inclination of his axis, are unknown.

NEPTUNE'S SATELLITE AND RING.

On July 8th, 1847, Mr. Lassell, of Liverpool, discovered a satellite of Neptune. Its period is about $5^d\ 20^h\ 51^m$. It moves in an orbit inclined to the ecliptic at an angle of about 28°, and at a mean distance of about 250,000 miles. The eccentricity of its orbit is so great, that its minor axis differs little from the planet's diameter. The time of the satellite's rotation on its axis is equal to that of its revolution round the planet. In common with the sixth satellite of Saturn it is much brighter in the preceding than in the following half of its path. This variation seems to show that one side of the satellite has less power of reflecting light than the other.

It has been ascertained that Neptune is surrounded by a ring, the ratio of whose diameter to that of the planet is about 3 to 2.

OF COMETS.

Besides the planets there are numerous bodies called *comets*, revolving round our sun, of the nature and orbits of which but little is known. Of upwards of 130, which have been accurately noted, only three have been identified, as having previously been observed: the comet of 1835, called Halley's comet, whose period is about 76 years; Encke's comet, whose period is $3{\cdot}3^y$; and Biela's comet, whose period is $6{\cdot}75^y$. The orbits of comets appear to be ellipses of so great eccentricity, that through the greater part of their orbits they are invisible from their great distance.

The attraction of the sun upon each of the planets is so overwhelming, that the attraction of the other planets produces but slight alterations in its orbit. Further, these disturbances so compensate one another that after a long period the planets recommence precisely the same paths in every respect. The planetary system is hence said to be *stable*. Owing, however, to the tenuity of the substance of comets, the planets exercise very great influence upon the form of their orbits, which influences, owing to the peculiar paths of the comets, do not compensate each other: hence the orbits of comets are liable to perpetual changes, and their system is consequently said to be *unstable*.

THE PHYSICAL CONSTITUTION OF COMETS.

Comets consist of a very diffuse vaporous mass, one part of which appears more condensed than the rest: this is termed the *nucleus* or *head.* The body is sometimes spread round this nucleus in a nearly circular form, sometimes extends to a great distance in the form of a long train, termed the *tail.* This tail is always in a direction opposite to that in which the sun is situated. The densest part of a comet is so thin, that stars of the smallest magnitude are distinctly visible through it. Indeed, so slight is the mass of a comet, that even the smallest satellites exercise great influence in determining a comet's course, without being themselves sensibly affected by its attraction. Not only do comets vary much in magnitude, but even the same comet undergoes very great changes, both in form and size, during its progress in its orbit. The tail of the comet of 1680, immediately after its perihelion passage, was found by Newton to be 60,000,000 miles in length. Its greatest length was 123,000,000 miles, a length much exceeding the earth's distance from the sun.

CHAPTER VI.

Of the Phases of the Moon; and of Solar and Lunar Eclipses.

THE PHASES OF THE MOON.

THE sun's distance from the earth is nearly 200 times the diameter of the moon's orbit; hence lines drawn from the sun to any part of the moon's orbit are so nearly parallel, that they may be considered as precisely so. In *Plate* II. *Fig.* 1., the large body in the centre represents the earth; the dotted ellipse the moon's path round the earth; on this path are represented eight different positions of the moon in her orbit; in all these positions she presents the appearance given in the figure, in which it will be observed that the plane dividing her bright and dark hemispheres moves always parallel to itself.

When she is in conjunction, her bright hemisphere is turned away from the earth, and she is consequently invisible. This position is commonly termed that of *change*, or *new moon*. When she is in opposition, the whole of her bright hemisphere is presented to us; she is then said to be *full*. At the quadratures, half her illuminated hemisphere is presented to the earth. Her phase is then that of *half-moon*. Half-way between conjunction and the quadratures, one quarter of her bright surface is visible from the earth; half-way between the quadratures and opposition, three-quarters. These points are termed *octants*. The proportions of dark and illuminated surface presented to the earth in these several positions are represented by the discs outside the dotted ellipse. It will be seen that, between new moon and the quarters, the moon's phase is *horned;* between full moon and the quarters, *gibbous*.

When the moon is nearly new to the earth, the earth is nearly full to the moon; she is then strongly illuminated by the reflection of the sun's light from the earth: a portion of this light is reflected back to the earth; hence, when the moon is near conjunction, and her crescent very small, a faint light is seen to illuminate the rest of her hemisphere. When the moon is nearer the quarters, a smaller proportion of the earth's bright side is presented to her, and this pale light dies away. This phenomenon is vulgarly called the old moon under the new moon's arm; the French term it "*la lumière cendrée*," the ashy light.

The moon is invisible when her position in the heavens is within a distance of about 30° of the sun. Now, a synodical month being about $29^{d}\ 12\frac{3}{4}^{h}$, her daily apparent motion exceeds that of the sun by about $12°\ 11\frac{1}{2}'$. Hence she is invisible for rather less than five days in every month.

The moon's horns, as shown in the figure, are always turned from the sun; hence in the first quarter they are turned towards the east, in the last towards the west.

ECLIPSES.

The earth and moon, being opaque bodies, intercept the sun's light, and throw behind them in space a shadow which consists of two parts, one, entirely dark, in which the whole light of the sun is intercepted; another, surrounding the above, in which only part of the sun's rays are intercepted: these are respectively called the *umbra* and *penumbra*. When any place on the earth's surface comes within the region of the moon's umbra or penumbra, the sun is said to be totally or partially eclipsed at that place.* When the moon comes within the earth's umbra or penumbra, a total or partial eclipse of the moon takes place.

The sun being larger than the earth or moon, their umbræ are of the form of a cone, of which the base is the intercepting body, and the apex is turned away from the sun. The penumbra, as shown in *Plate* II. *Fig.* 6., is of the form of a truncated cone, the imaginary apex of which lies between the body and the sun. Thus in the figure, HGED is the earth's penumbra.

Solar Eclipses.

To persons situate within the moon's umbra, as between *e* and *f*, the sun is totally eclipsed. Those for a certain distance around will see a partial eclipse. Sometimes, however, the moon is so far from the earth, that the apex of her umbra falls between the sun and the earth: in this case those in or near a straight line drawn through the centres of the sun and moon see a ring of light round the dark body of the moon: this is termed an annular eclipse. The further persons are situate from this line, the more uneven is the breadth of the ring: those at a certain distance see only the usual appearance of a partial eclipse. Sometimes part of the earth's surface falls within the moon's penumbra, but none within her umbra; in this case the eclipse is everywhere partial. The moon being smaller than the earth, the same eclipse is visible to only a portion of the earth's enlightened hemisphere. The umbra can never cover a space of more than 180 miles diameter on the earth's surface: the penumbra may cover a circle of a diameter of 4900 miles.

If the moon be exactly in her node, that is, if, when she crosses the ecliptic, her centre is in a direct line with those of the sun and moon, the centre of her shadow will pass over the centre of the earth's disc, and will describe a diameter of its disc, or great circle of its sphere. In any other total solar eclipse, the centre of the moon's shadow will describe a chord of its disc, or small circle of its sphere, the length of the chord varying according to the moon's latitude: hence the duration of a solar eclipse depends on the length of the line which the centre of her shadow describes, the distance of the moon from the earth (on which depends the extent of the umbra), and the velocity of the moon's motion. These two last, by Kepler's law, vary together. To find the duration of an eclipse at any particular place, the distance of the place from the line described by the centre of the umbra must be further taken into account. Nowhere on the earth's surface can an eclipse be annular longer than 12^{m} 24″, or total longer than 7^{m} 58″.

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* A solar eclipse would with more correctness be termed an *occultation* of the sun.

LUNAR ECLIPSES.

An eclipse of the moon being caused by her entering the earth's shadow cannot happen but when the moon is in opposition. The earth being much larger than the moon, her shadow is broader than the moon's diameter; consequently there can be no such thing as an annular eclipse of the moon. A solar eclipse, being caused by the moon's shadow, is visible to those parts of the earth only upon which the shadow is cast. A lunar eclipse, on the contrary, being an actual obscuration of the moon, is visible to all on the earth's surface who can see the moon.

The length of an eclipse of the moon varies according to the breadth of the part of the earth's shadow crossed by her, and the velocity with which she crosses it. Hence, it depends on the moon's latitude, and on her distance from the earth. The duration, from the time of her first touching the earth's penumbra to the time of her leaving it, cannot exceed $5\frac{1}{2}^{h}$. The moon cannot be totally eclipsed longer than $1\frac{3}{4}^{h}$.

CONDITIONS OF AN ECLIPSE.

Were the orbit of the moon in the same plane with that of the earth, there would be one solar eclipse and one lunar eclipse every month. The moon's orbit is, however, inclined to the ecliptic at an angle of 5° 8′ 48″. Hence, unless the moon is at or near the node at the time of conjunction or opposition, there can be no eclipse. It has been calculated, that if at the time of conjunction the moon's node is further in longitude from the sun than 16° 58′, there can be no eclipse of the sun; if at the time of opposition the moon's node is further from the sun than 11° 34′, there can be no eclipse of the moon. These angular distances are called the solar and lunar ecliptic limits.

NUMBER OF ECLIPSES IN A YEAR.

The sun moves on the ecliptic at the rate, roughly speaking, of 29° in a synodical month. Now the ecliptic limits of the sun are 16° 58′ on either side of the node, or about 33° altogether. Hence, the solar ecliptic limit being greater than the sun's monthly advance on the ecliptic; it is clear that the sun must be eclipsed once, and may be eclipsed twice, on passing each node. If the sun is twice eclipsed, it must be at a nearly equal distance on either side of the node at each eclipse; hence, at the intervening full moon it will be nearly in the node, and, consequently, if there are two eclipses of the sun at one passage of the node, there will be an intervening eclipse of the moon. If, however, the sun is in the node at the time of the new moon, it must at the preceding and following full moons be about 14½° from the node, and consequently beyond the lunar ecliptic limit: at the preceding and following new moons, it must be about 29° from the node, and consequently beyond the solar ecliptic limit. In this case there will be only one eclipse of the sun and none of the moon. It will be seen that there cannot be more than one lunar eclipse at the passage of each node.

The sun occupies 173^d in passing from one node to another. Hence it must pass both nodes in the course of a year, and since at least one eclipse (a solar one) must take place at each passage of the node, there must be at least two eclipses, both solar ones, every year. The more usual number, however, at each passage of the node, being one of each kind, there usually happen four eclipses yearly, two of the sun, and two of the moon.

When three eclipses fall about either node, the same number usually falls about the opposite node, since the time of the sun's passage from node to node is within four days of the time occupied by six lunations. Hence, there may be four eclipses of the sun, and two of the moon, in the course of two passages of the node. In order that all these may fall in one year, neither nodical passage must be within a fortnight of either end of the year. Hence, although a third nodical passage takes place at an interval of 346^d from the first, there will not be time for more than one more eclipse, a solar one, to take place within 365^d. Hence, the greatest possible number of eclipses in a year is seven, five of the sun, and two of the moon.

Although in this particular case only two eclipses are lunar, yet since there may be lunar eclipses at three successive nodical passages, all falling within the same year, there may be three lunar eclipses in a year. Since, however, there cannot be more than one lunar eclipse at each nodical passage, nor more than three nodical passages yearly, the above is the greatest possible number of lunar eclipses.

Hence, *there cannot be more than seven eclipses in a year, nor fewer than two. There cannot be more than five solar eclipses, nor fewer than two. There cannot be more than three lunar eclipses, and there may be none. The usual number of eclipses is four, two lunar, and two solar.*

The solar ecliptic limits are to the lunar nearly in the proportion of 3 to 2 ; hence, the number of solar eclipses exceeds the number of lunar in that proportion. A solar eclipse, however, is visible but to a comparatively small part of the earth's surface, whereas a lunar eclipse is visible to a whole hemisphere. Hence, at a given place, and within a given time, there is a greater probability of seeing a lunar than a solar eclipse.

The Cycle of Eclipses.

It has been shown, that after a period of 18·6^{y} the moon recommences precisely the same spiral path in the heavens, and the same series of occultations of the fixed stars. Did the sun remain stationary in the heavens, she would also, after that period, recommence the same series of solar and lunar eclipses. The sun performs a circuit of the heavens in a year, hence he will not be in the same place at intervals of 18·6^{y}. But it is found that at the end of the nineteenth year, when of course the sun has arrived at the same place in the heavens, the moon's longitude also is the same that it was 19^{y} before. Also, since only ·4^{y}, or about ·002 of her whole cycle, has elapsed since the recommencement of her journey, her path in the heavens is almost the same as at the beginning of the cycle. Hence, with a very slight difference, the sun and moon will have, relatively to the earth, the positions which they had nineteen years before, and the eclipses which happened then will happen again, almost exactly the same in every respect. This cycle of the moon is said to have been discovered by Meton, an Athenian, B.C. 433. The number, marking the position of any year in the cycle, was marked in letters of gold on the temple of Minerva, and has ever since retained the name of the Golden Number. A rule, by which the Golden Number for any year may be found, is given in the following chapter.

TABLE TO FIND THE MOON'S AGE BY INSPECTION.

MONTHS.									YEARS.																		
Jan.	Feb. April.	Mar.	May.	June	July.	Aug.	Sept. Oct.	Nov. Dec.	1800 1819 1838 1857 1876	1801 1820 1839 1858 1877	1802 1821 1840 1859 1878	1803 1822 1841 1860 1879	1804 1823 1842 1861 1880	1805 1824 1843 1862 1881	1806 1825 1844 1863 1882	1807 1826 1845 1864 1883	1808 1827 1846 1865 1884	1809 1828 1847 1866 1885	1810 1829 1848 1867 1886	1811 1830 1849 1868 1887	1812 1831 1850 1869 1888	1813 1832 1851 1870 1889	1814 1833 1852 1871 1890	1815 1834 1853 1872 1891	1816 1835 1854 1873 1892	1817 1836 1855 1874 1893	1818 1837 1856 1875 1894
DAYS.									MOON'S AGE.																		
1 31	29	30	28	27	26	25	23	21	5	16	27	8	19	1	12	23	4	F	26	7	18	29	10	21	2	13	24
2	30	1 31	29	28	27	26	24	22	6	17	28	9	20	2	13	24	5	16	27	8	19	N	11	22	3	14	25
3	1	2	30	29	28	27	25	23	7	18	29	10	21	3	14	25	6	17	28	9	20	1	12	23	4	F	26
4	2	3	1 31	30	29	28	26	24	8	19	N	11	22	4	F	26	7	18	29	10	21	2	13	24	5	16	27
5	3	4	2	1	30	29	27	25	9	20	1	12	23	5	16	27	8	19	N	11	22	3	14	25	6	17	28
6	4	5	3	2	1 31	30	28	26	10	21	2	13	24	6	17	28	9	20	1	12	23	4	F	26	7	18	29
7	5	6	4	3	2	1 31	29	27	11	22	3	14	25	7	18	29	10	21	2	13	24	5	16	27	8	19	N
8	6	7	5	4	3	2	30	28	12	23	4	F	26	8	19	N	11	22	3	14	25	6	17	28	9	20	1
9	7	8	6	5	4	3	1	29	13	24	5	16	27	9	20	1	12	23	4	F	26	7	18	29	10	21	2
10	8	9	7	6	5	4	2	30	14	25	6	17	28	10	21	2	13	24	5	16	27	8	19	N	11	22	3
11	9	10	8	7	6	5	3	1 31	F	26	7	18	29	11	22	3	14	25	6	17	28	9	20	1	12	23	4
12	10	11	9	8	7	6	4	2	16	27	8	19	N	12	23	4	F	26	7	18	29	10	21	2	13	24	5
13	11	12	10	9	8	7	5	3	17	28	9	20	1	13	24	5	16	27	8	19	N	11	22	3	14	25	6
14	12	13	11	10	9	8	6	4	18	29	10	21	2	14	25	6	17	28	9	20	1	12	23	4	F	26	7
15	13	14	12	11	10	9	7	5	19	N	11	22	3	F	26	7	18	29	10	21	2	13	24	5	16	27	8
16	14	15	13	12	11	10	8	6	20	1	12	23	4	16	27	8	19	N	11	22	3	14	25	6	17	28	9
17	15	16	14	13	12	11	9	7	21	2	13	24	5	17	28	9	20	1	12	23	4	F	26	7	18	29	10
18	16	17	15	14	13	12	10	8	22	3	14	25	6	18	29	10	21	2	13	24	5	16	27	8	19	N	11
19	17	18	16	15	14	13	11	9	23	4	F	26	7	19	N	11	22	3	14	25	6	17	28	9	20	1	12
20	18	19	17	16	15	14	12	10	24	5	16	27	8	20	1	12	23	4	F	26	7	18	29	10	21	2	13
21	19	20	18	17	16	15	13	11	25	6	17	28	9	21	2	13	24	5	16	27	8	19	N	11	22	3	14
22	20	21	19	18	17	16	14	12	26	7	18	29	10	22	3	14	25	6	17	28	9	20	1	12	23	4	F
23	21	22	20	19	18	17	15	13	27	8	19	N	11	23	4	F	26	7	18	29	10	21	2	13	24	5	16
24	22	23	21	20	19	18	16	14	28	9	20	1	12	24	5	16	27	8	19	N	11	22	3	14	25	6	17
25	23	24	22	21	20	19	17	15	29	10	21	2	13	25	6	17	28	9	20	1	12	23	4	F	26	7	18
26	24	25	23	22	21	20	18	16	N	11	22	3	14	26	7	18	29	10	21	2	13	24	5	16	27	8	19
27	25	26	24	23	22	21	19	17	1	12	23	4	F	27	8	19	N	11	22	3	14	25	6	17	28	9	20
28	26	27	25	24	23	22	20	18	2	13	24	5	16	28	9	20	1	12	23	4	F	26	7	18	29	10	21
29	27	28	26	25	24	23	21	19	3	14	25	6	17	29	10	21	2	13	24	5	16	27	8	19	N	11	22
30	28	29	27	26	25	24	22	20	4	F	26	7	18	N	11	22	3	14	25	6	17	28	9	20	1	12	23

By the inspection of the table on the preceding page, the moon's age may be found for any day from the year 1800 to the year 1894 inclusive, in the following manner:—Find the proposed day under the given month; on the same horizontal line, under the given year, will be found the moon's age, as required. N stands for new, F for full moon.

EXAMPLE. Required the moon's age on the 14th of August, 1848. Even with the day of the month found in the first part of the Table, and under the year 1848 in the latter part, is found the letter F, which shows that the moon is full on that day.

In like manner, it will be found that upon the 10th of June, 1848, the moon's age is 10 days.

In the following Table the right-hand column annexed to the moon's age is used in finding the time of high water in the succeeding problems relating to that subject. (See Part III.)

Moon's Age.	High Water.		Moon's Age.	High Water.		Moon's Age.	High Water.	
Days.	H.	M.	Days.	H.	M.	Days.	H.	M.
0	0	0	11	9	17	21	15	56
1	0	36	12	10	9	22	16	51
2	1	11	13	10	53	23	18	0
3	1	46	14	11	33	24	19	18
4	2	21	15	12	8	25	20	31
5	3	1	16	12	45	26	21	31
6	3	44	17	13	19	27	22	21
7	4	37	18	13	54	28	23	3
8	5	40	19	14	30	29	23	42
9	6	58	20	15	11	29½	24	0
10	8	14						

CHAPTER VII.

Of the Calendar.

To facilitate the computation of time for the common purposes of life, the use of certain standard measures has, in every nation, been agreed upon. A table of such measures is termed a *Calendar*. The alternations of day and night, the periodical recurrence of the same phases of the moon, and the changes of the seasons, early suggested the division of time into days, months, and years. The difficulty of adjusting these measures to one another has given rise to various modifications of them in different ages and countries. An additional division of time into periods of seven days, called *weeks*, has been in use, in most countries, from the earliest times, having been originally instituted by divine command.

The length of the true solar day (see Def. 56.) is subject to great variation, the difference between its greatest and least length being upwards of thirty-two minutes. It being very necessary that any measure of time in common use should be uniform, the average length of the true solar day is taken. This is called a mean solar day, and is divided into twenty-four hours.

Time was, in very early ages, measured by the revolutions of the moon. Indeed this division, and that into days and nights, are found in use among savage nations, who are unacquainted with any other standard of computation, and even some civilised nations have followed a lunar chronology exclusively. The Turks and Jews still continue to do so, making the year consist of 13 lunar months, or 355 days. We, however, in common with most modern nations, although preserving the lunar chronology in name, have entirely laid it aside in fact, our calendar months, and months of four weeks, commencing indifferently at any period in the moon's revolution.

The calendar at present in use in this country is called the Gregorian Calendar. As it is founded on the Julian Calendar, it will be best to commence with an account of the latter.

In the earlier periods of Roman History, the lunar year above-mentioned was in use, arbitrary intercalations being made from time to time, in order that its commencement might correspond with that of the solar year. The confusion and error caused by this clumsy mode of reckoning were so great, that in the time of Julius Cæsar, the civil year was ninety days in advance of the solar. Ascertaining from an Alexandrian astronomer, named Sosigenes, that the solar year was about $365\frac{1}{4}^d$ in length, he made the usual civil year to consist of 365^d, another day being added to every fourth year.[*] This additional day was inserted after Feb. 24th, which, according to the backward mode of reckoning of the Romans, was called *sextus ante Calendas Martias*, that is, the sixth day before the 1st of March. Hence the leap year, having two such days, was called *bissextĭlis*. To reconcile the confusion already existing between the civil and solar years, it was further enacted that the previous year (B. C. 46) should consist of 455 days, whence it was called "the year of confusion."

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[*] "An error prevailed for thirty-seven years after the death of Cæsar from reckoning every third year a leap-year, as if the year contained 365^d 3^h. When the mistake was detected, thirteen intercalations had occurred instead of ten. It was, therefore, ordered that there should not be any leap-year for twelve years, *i. e.* until A. D. 7. From that time the years have been calculated without mistakes." — *Sir H. Nicholas*, Chronology of *History*, p. 4.

Since, however, the tropical year does not consist of $365\frac{1}{4}^{d}$, but only of $365^{d}\ 5^{h}\ 48^{m}\ 49''\cdot7$, the Julian year was too long by about $11^{m}\ 10''$. Hence, in course of time, the solar year was found to be sensibly in advance of the civil year. This error had, in the sixteenth century, increased to ten days. To rectify it, Pope Gregory XIII. published a bull, commanding the omission of ten days after October 4th, 1582, so that the next day was called the 15th instead of the 5th. To prevent the recurrence of such error for the future, he further ordered that every hundredth year, instead of being a leap-year, should consist, like the rest, of 365^{d}, with the exception of every four-hundredth year, which was to be a leap-year as before. Thus the years 1600, 2000, &c. were to be leap-years; 1700, 1800, 1900, 2100, &c. years of the usual length.

Let us see how far this rule differs from the truth. In the Julian computation there was, as has been shown, a yearly excess of $11^{m}\ 10''\cdot3$ or $\cdot00776^{d}$. Hence, after the lapse of a century, the solar year was $\cdot776^{d}$, or about $18^{h}\ 3\frac{1}{4}^{m}$ in advance of the civil. The omission of the leap-day in every hundredth year produces an error on the other side of $\cdot224^{d}$, or about $5^{h}\ 56\frac{1}{4}^{m}$. This, in four centuries, brings the civil year $\cdot896^{d}$, or about $21\frac{1}{2}^{h}$ in advance of the solar. The restoration of the leap-day to every four hundredth year produces a contrary error of $\cdot104^{d}$, or about $2\frac{1}{2}^{h}$. This error, recurring, as it does, but once in 400 years, was considered too slight to be taken into account. Indeed, in 4000 years, it will amount but to $1\cdot04^{d}$, or about $1^{d}\ 5\frac{3}{4}^{m}$. Had, however, the Gregorian correction advanced a step further, and declared that every four thousandth year should consist of 365^{d} only, the difference between the solar and Gregorian calendars would have been reduced to $\cdot04^{d}$, or about $5\frac{3}{4}^{m}$ in 4000 years, an error which would take 100,000 years to amount to a day.

The length of the tropical year was stated to be $365^{d}\ 5^{h}$ $48^{m}\ 49''\cdot7$. This is not absolutely correct. Owing to the motion of the equinoctial points, the tropical year slightly varies in length, being now above $4''{\cdot}21$ shorter than in the time of Hipparchus. This error is obviously too slight to be taken into consideration for any practical purpose.

The Gregorian Calendar, being introduced by a pope, was at once adopted in all Roman Catholic countries. Protestant nations for a long time rejected it. It was not introduced into the north of Germany until 1699, nor into England until 1752, at which time, the year 1700 having intervened since the correction was made by Pope Gregory, it was necessary to omit eleven days from the calendar instead of ten. Accordingly September 3rd and the ten following days were omitted for that year. Previously to that time the English year had commenced on March 25th. It was then enacted that the year 1752, and all following years, should be held to commence on January 1st. Hence it is that we meet, in historical works, with such dates as Jan. $174\frac{5}{6}$, by which is meant the month of January, which, according to the old reckoning, was considered part of 1745, according to the new would have been assigned to 1746.

The Russians, and other members of the Greek church, are the only Europeans who still adhere to the Julian Calendar, or Old Style. The year 1800 having elapsed since the alteration was made in England, their dates are twelve days in arrear of those of the English and others, who have adopted the Gregorian Calendar, or New Style. Thus Jan. 1st, O. S., which, in the last century, corresponded with Jan. 12th, N. S., corresponds in this century with Jan. 13th, N. S.

The *Common Notes* for the year usually given in our Almanacs are, *the Cycle of the Moon, or Golden Number* (see p. 232.); *the Epact; the Cycle of the Sun and the Dominical Letter; the Number of Direction; and the Roman Indiction.**

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* The Roman Indiction is of no use whatever in the Calendar. It was a period of 15 years, in which the Romans collected a tax from the countries which they had conquered. To find the Roman Indiction add 3 to the year of Christ, and divide the sum by 15; the remainder is the Indiction. Thus, the Indiction for 1845 is 3, for $(1845 + 3) \div 15$ leaves a remainder of 3.

The *Julian Period* is of no use in the calendar; however, it may be found by adding 4713 to the year of Christ. Thus, for the year 1844 we have $1844 + 4713 = 9557$, the year of the Julian period.

I. *The Cycle of the Moon* is a period of nearly 19 years, (*see p.* 232.) after which the new and full moons fall on the same day of the month as they did at the beginning of the period. Any number of this period is called the *Golden Number.*

To find the Golden Number for any Year.

RULE.—Add 1 to the given year, and divide the sum by 19, the remainder is the Golden Number. If there be no remainder, the Golden Number is 19.

Example.—What is the Golden Number for the year 1850?

(1850+1)÷19 leaves a remainder of 8, which therefore is the Golden Number.

II. *The Epact for any Year* is the moon's age at the beginning of that year; that is, the number of days which have elapsed since the last new moon in the preceding year. Its use is to find the *Paschal full moon.*

To find the Epact for any Year till 1900.

RULE.—Find the Golden Number and subtract 1 from it, multiply the remainder by 11, and the product will be the Epact; if the product exceed 30, divide it by 30, and the remainder will be the Epact. When the Golden Number is 1, the Epact is 29.

Example.—What is the Epact for the year 1850?

The Golden Number for 1850 is 8, hence (8—1)×11=77÷30=2, with a remainder of 17, which *last* is the Epact for 1850.

In the table on page 233, the epact for any year is the last number in the column under that year.

A TABLE of the Epacts till the Year 1900.

Golden Numbers.	Epacts.	Golden Numbers.	Epacts.	Golden Numbers.	Epacts.	Golden Numbers.	Epacts.
1	XXIX.	6	XXV.	11	XX.	16	XV.
2	XI.	7	VI.	12	I.	17	XXVI.
3	XXII.	8	XVII.	13	XII.	18	VII.
4	III.	9	XXVIII.	14	XXIII.	19	XVIII.
5	XIV.	10	IX.	15	IV.		

III. *The Cycle of the Sun* is a period of 28 years, after which the days of the month return to the same days of the week. This cycle has no reference to the apparent motion of the sun, its chief use being to find the Dominical Letters.

In order to connect the days of the week with the days of the year, the first *seven* letters of the alphabet are chosen to mark the several days of the week. These letters are arranged in such a manner for every year, that the letter A stands for the first of January, B for the second, C for the third, and so on. The seven letters being constantly repeated in their order through all the days of the year, it is plain that the same letter will answer to Sunday throughout the whole year, which is therefore called the *Sunday* Letter.

To find the Cycle of the Sun for any Year till 1900, *and likewise the Sunday Letter.*

RULE.—Add 9 to the given year, and divide the sum by 28, the remainder is the year of the solar cycle; if there be no remainder, the solar cycle is 28. Then in the following Table, against the solar cycle you will find the Dominical Letter.

1 ED	5 GF	9 BA	13 DC	17 FE	21 AG	25 CB
2 C	6 E	10 G	14 B	18 D	22 F	26 A
3 B	7 D	11 F	15 A	19 C	23 E	27 G
4 A	8 C	12 E	16 G	20 B	24 D	28 F

In a leap-year there are two Sunday Letters; the left-hand letter is used till the end of February, and the other till the end of the year.

Example.—What is the Dominical Letter for 1850? $(1850+9) \div 28$ leaves a remainder of 11; hence by the above table F is the Sunday Letter.

OR, To the given year add its fourth part, omitting fractions, and increase the sum by 6, divide the result by 7, and the remainder taken from 7 leaves the *number* of the letter; reckoning A to be 1, B 2, C 3, D 4, E 5, F 6, and G 7. In a leap-year this rule always gives the letter answering to the months after February.

Example.—$1849 + \frac{1849}{4} + 6 = 2317$, which, divided by 7, leaves no remainder; hence G is the Sunday letter.

Again; $1851 + \frac{1851}{4} + 6 = 2319 = \frac{331}{7} + 2$; $7 - 2 = 5$; hence the Sunday letter for 1851 is E.

IV. The *Number of Direction* is a number to be added to the 21st of March to show on what day of the month *Easter Sunday* falls. The *earliest Easter* possible is the 22nd of March, the *latest* the 25th of April. Within these limits are 35 days, and the number of direction varies from 1 to 35. Thus, if Easter Sunday falls on the 22nd of March the number of direction is 1, if on the 23rd it is 2; and so on to the 31st, when the number of direction is 10. If Easter Sunday falls on the first of April, the number of direction is 11, if on the second it is 12, and so on to the 25th of April, when the number of direction is 35.

A TABLE showing the number of Direction for finding Easter Sunday by the *Golden Number* and *Dominical Letter.*

G. N.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Domini. Letters.	A	26	19	5	26	12	33	19	12	26	19	5	26	12	5	26	12	33	19	12
	B	27	13	6	27	13	34	20	13	27	20	6	27	13	6	20	13	34	20	6
	C	28	14	7	21	14	35	21	7	28	21	7	28	14	7	21	14	28	21	7
	D	29	15	8	22	15	29	22	8	29	15	8	29	15	1	22	15	29	22	8
	E	30	16	2	23	16	30	23	9	30	16	9	23	16	2	23	9	30	23	9
	F	24	17	3	24	10	31	24	10	31	17	10	24	17	3	24	10	31	17	10
	G	25	18	4	25	11	32	18	11	32	18	4	25	18	4	25	11	32	18	11

Example.—On what day of the month does *Easter Sunday* fall in the year 1850?

The Golden Number already found is 8, and the Sunday Letter F. Under 8, and in a line with F in the preceding Table, you will find 10, which is the *number of direction.* Easter Sunday falls therefore on the 8th of April, which is 18 days in advance of the 21st of March.

To find the PASCHAL FULL MOON, *and thence Easter Day by the Epact.*

Add 6 to the Epact (if this sum exceeds 30, 30 must be taken from it), and subtract the sum from 50; the remainder is the *Paschal full moon*, or Easter limit. Add 4 to the number of the Dominical letter, subtract the sum from the limit, and the remainder from the next higher number, which will divide even by 7. The last remainder added to the limit will give the number of days from the first of March to Easter Day, both inclusive.

Example.—Find the Paschal full moon and Easter Day for the year 1850.

The Epact already given is 17, then 50−(17+6)=27, Easter limit or Paschal full moon. The Dominical letter is F; hence the number of the letter is 6, and 27−(6+4)=17, the next higher number to which divisible by 7 without a remainder is 21. Therefore, 21−17=4; then 4 being added to 27, the limit gives 31, the days from the 1st of March; hence Easter day is the 31st of March as before.

A TABLE for finding Easter till the Year 1900.

Epacts.	Paschal Full Moons.	Epacts.	Paschal Full Moons.
XXIX.	13 April E.	IX.	4 April C.
XI.	2 April A.	XX.	24 March F.
XXII.	22 March D.	I.	12 April D.
III.	10 April B.	XII.	1 April G.
XIV.	30 March E.	XXIII.	21 March C.
XXV.	18 April C.	IV.	9 April A.
VI.	7 April F.	XV.	29 March D.
XVII.	27 March B.	XXVI.	17 April B.
XXVIII.	15 April G.	VII.	6 April E.
		XVIII.	26 March A.

THE USE OF THE TABLE.—Find the Epact (by some of the preceding methods), against which, in the Table, is the day of the Paschal full moon, with its corresponding weekly letter.

Example.—On what day does Easter Sunday fall in the year 1850?

The Epact is 17, against which, in the Table, is the 27th of March, the day of the Paschal full moon; and this happens on a Wednesday, as indicated by the letter B; B being the Sunday letter for the year; hence Easter Sunday falls on the 31st of March.

Easter Sunday being found, all the moveable feasts which depend upon it are known.

Septuagesima Sunday is 9 weeks	Before Easter.
Sexagesima Sunday is 8 weeks	
Shrove Sunday or *Quinquagesima Sunday* is 7 weeks	
Shrove Tuesday and *Ash Wednesday follow* Quinquagesima Sunday	
Quadragesima Sunday is 6 weeks	
Palm Sunday a week	
Good Friday two days	
Low Sunday is 1 week	After Easter.
Rogation Sunday is 5 weeks	
Ascension Day or *Holy Thursday* the Thursday following Rogation	
Whit Sunday is 7 weeks	
Trinity Sunday is 8 weeks	

Then follow all the Sundays after Trinity in order. The Sundays between Ash Wednesday and Easter are called Sundays in Lent; and the Sundays between Easter and Whit Sunday are called Sundays after Easter.

V. By Act of Parliament *Easter Day* is the first Sunday after the full moon which happens upon, or next after, the 21st of March; and if the full moon fall on a Sunday, *Easter Day* is the Sunday after.*

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* The astronomical full moon does not always exactly coincide with the Paschal full moon, as established by the authorised tables. Thus, in the year 1845, the *astronomical* full moon was on Sunday the 23rd of March, but the *calendar* full moon was on Saturday the 22nd; consequently Easter day was the Sunday following, viz. the 23rd.

I. THE SUN AND THE ZODIACAL PLANETS.

	Sun.	Mercury.	Venus.	Earth.	Mars.	Jupiter.	Saturn.	Uranus.	Neptune.
Mean distance from sun in earth's distances -	—	0·3871	0·7233	1·0000	1·5236	5·2028	9·5387	19·1824	30·2026
Sidereal period in solar days (Neptune's in earth's sidereal years) - - -	—	87·969	224·701	365·256	686·980	4332·585	10759·22	30686·82	165·978
Inclination of orbit to ecliptic - - -	—	7° 0′ 9″·1	3° 23′ 28″·5	—	1° 51′ 6″·2	1° 18′ 51″·3	2° 29′ 35″·7	0° 46′ 28″·4	1° 47′ 1″·5
Longitude of ascending node (Neptune Jan. 1. 1847, the rest Jan. 1. 1801) - -	—	45° 57′·5	74° 54′·2	—	48° 0′	98° 26′·3	111° 56′·6	72° 59′·6	130° 5′·6
Time of rotation on axis - - -	25^{d} 10^{h}	24^{h} 5′ 3″	23^{h} 21′ 19″	24^{h}	24^{h} 39′ 21″	9^{h} 55′ 50″	10^{h} 16^{m}	Unknown	Unk.
Inclination of axis to orbit - - -	82° 40′	Unknown.	15°	66° 32′	61° 33′	86° 55′	60°	11° ?	Unk.
Diameter (earth's being unity) - - -	111·5	0·39	0·97	1	0·56	11·56	9·61	4·26	15 ?
Volume (earth's being unity) - - -	1,384,472	0·06	0 91	1	0·17	1470	887·30	77·30	230 ?
Density (earth's being unity) - - -	0·26	2·95	0·99	1	0·79	0·23	0·11	0·26	Unk.
Mass (earth's being unity) - - -	359,963	0 17	0·89	1	0·14	339·30	101·10	19·81	Unk.

II. THE ULTRA-ZODIACAL PLANETS.

	Vesta.	Hebe.	Astræa.	Juno.	Ceres.	Pallas.
Mean distance from sun in earth's distances - -	2·37	2·5	2·6	2·67	2 767	2·773
Sidereal periods in solar days - - - -	1325·7	1461·5	1524	1592·6	1681·3	1686·5
Inclination of orbit to ecliptic - - - -	7° 8′ 9″	15° 3′	5° 20′	13° 4′ 9″	10° 37′ 26″	34° 34′ 55″
Diameter in earth's diameters - - - -	0·034 ?	—	—	0·17 ?	0·05 ?	0·01 ?

III. THE SATELLITES.*

	Mean dist. in equatorial radii of primary.	Sidereal revolution.			Inclination of orbit to orbit of primary.	Mas term mass prim
The Moon - - -	59·982175	27^{d}	7^{h}	43′	5° 8′ 47″·5	0·012
Satellites of Jupiter - I.	6·04853	1	18	28	3° 5′ 30″	0·000
II.	9·62347	3	13	14	Variable.	0·000
III.	15·35024	7	3	43	Variable.	0·000
IV.	26·99835	16	16	32	2° 58′ 48″	0·000
Satellites of Saturn - I.	3·351	0	22	38	The orbits of the six interior satellites are very nearly in the plane of the ring, that of the seventh approaches nearer to coincidence with the ecliptic.	
II.	4·300	1	8	53		
III.	5·284	1	21	18		
IV.	6·819	2	17	45		
V.	9·524	4	12	25		
VI.	22·081	15	22	41		
VII.	64·359	79	7	55		
Satellites of Uranus I. ?	13·120	5	21	25	Their orbits are inclined about 78° 58′ to the ecliptic, and their motion is retrograde.	
II.	17·022	8	16	56		
III. ?	19·845	10	23	4		
IV.	22·752	13	11	9		
V. ?	45·507	38	1	48		
VI. ?	91·008	107	16	40		
Satellite of Neptune -	4·25 ?	5	20	5	About 18° 13′	

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* Taken, with the exception of the elements of Neptune's satellite, from the Ta at the end of Herschel's Astronomy.

PART III.

CONTAINING PROBLEMS PERFORMED BY THE TERRESTRIAL AND CELESTIAL GLOBES.

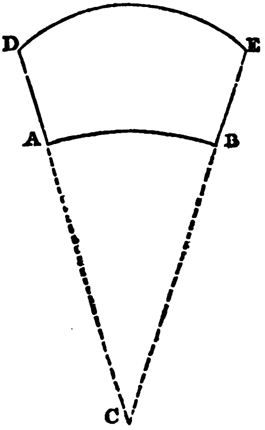
Chapter I.

Problems performed by the Terrestrial Globe.

PREPARATORY PROBLEM.

To cut a card so as to coincide with the convex surface of the globe and the graduations on the brazen meridian.

Rule. With the semi-diameter of the globe for a radius (that is, with a radius of six inches for a twelve-inch globe, nine inches for an eighteen-inch globe, and so on), and any point, C, as a centre, describe the arc A B of any convenient length. From C, through the points A and B, draw the lines C A D, C B E, and connect the points D and E with a plain or ornamental line: then if the figure A B D E be cut smoothly



out with any very sharp tool, the arc A B will fit the convex surface, and the sides A D, B E, will become produced radii of the globe, corresponding exactly with the divisions marked on the brazen meridian. This card for want of a better name, I have called an INDEX CARD.

The use of this card is to read off the brazen meridian correctly, as well as to preserve the globe from the injuries it frequently sustains from the pernicious custom of applying the point of a pair of compasses, &c., to its surface, particularly in working those problems that require a rotation of the globe on its axis, at the same time that a certain point of declination or latitude is preserved.*

PROBLEM I.

To find the latitude of any given place.

DIRECTION.

While working the examples in the following problems, the student is recommended to make himself perfectly acquainted with the precise meaning of every term used, as latitude, declination, altitude, &c., which he will find explained in the early pages of this treatise, and which may be readily referred to by consulting the Table of Contents immediately following the Preface. He is also particularly reminded that one half of the brass meridian is numbered from the equator to the poles. This is used to find the latitude and declination of the sun, and should be kept above the horizon. The other half is numbered from the poles to the equator, and is used *only* for elevating the poles, and should be kept below the horizon.

RULE. Bring the given place to the brass meridian: the degree directly above the place is the latitude. If the place be on the north side of the equator, the latitude is north; if it be on the south side, the latitude is south.*

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* In applying the Index Card, place the flat side of the card against the graduated side of the brazen meridian, while the concave edge rests on the surface of the globe; then, if one of the extreme ends of the concave arc be brought exactly to touch the given place, star, &c., the straight edge of the Index Card will cut the true latitude of the place or declination of the star, &c., which will be read off as correctly and easily as if the graduated edge of the meridian itself extended to the very surface of the globe. Any degree, or even a quarter of a degree of the equator, ecliptic, &c. intersected by the brazen meridian, may be read off with equal correctness and facility by a similar application of the Index Card.

EXAMPLES. What is the latitude of Edinburgh?

Answer. 56° north.

2. Required the latitudes of the following places:

Amsterdam
Archangel
Barcelona
Florence
Gibraltar
Hamburgh
Philadelphia
Quebec
Rio Janeiro.

3. Find all the places on the globe which have no latitude.

4. What is the greatest latitude a place can have?

PROBLEM II.

To find all those places which have the same latitude as any given place.

RULE. Bring the given place to the brass meridian, and observe its latitude; turn the globe round, and all places passing under the observed latitude are those required.

All places in the same latitude have the same length of day and night and the same seasons of the year, though, from local circumstances, they may not have the same atmospherical temperature.

EXAMPLES. 1. What places have the same, or nearly the same, latitude as Madrid?

Answer. Minorca, Naples, Constantinople, Samarcand, Philadelphia, Pekin, &c.

2. What inhabitants of the earth have the same length of days as the inhabitants of Edinburgh?

3. What places have nearly the same latitude as London?

4. What inhabitants of the earth have the same seasons of the year as those of Ispahan?

5. Find all places of the earth which have the longest day the same length as at Port Royal in Jamaica.

What places have the same latitude as the following?

6. Rio Janeiro
7. Quito
8. Cairo
9. Lima
10. Copenhagen
11. Petersburgh
12. Botany Bay
13. St. Helena
14. Paris.

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* Observe that in using either globe, it is to be so placed that the *graduated side* of the brazen meridian may be towards the right hand.

On maps, the figures which show the latitude are placed on the sides: if the figures increase upwards, the latitude is north; if downwards, south.

PROBLEM III.

To find the longitude of a place.

RULE. Bring the given place to the brass meridian, and the degree of the equator cut by the brass meridian will be the longitude. If the figures increase towards the right hand, the longitude is east; if towards the left, west.*

On many globes there are two rows of figures above the equator which show the longitude; those denoting the east as well as those showing the west longitude being carried quite round the globe. In this case those figures are to be used which are of the least amount.

EXAMPLES. 1. What is the longitude of Petersburgh?

Answer. 30¼° east.

2. What is the longitude of Philadelphia?

Answer. 75¼° west.

3. Required the longitudes of the following places:

Aberdeen
Alexandria
Barbadoes
Bombay
Botany Bay
Canton
Carlscrona
Cayenne
Civita Vecchia.

4. What is the greatest longitude a place can have?

PROBLEM IV.

To find all those places that have the same longitude as a given place.

RULE. Bring the given place to the brass meridian, then all places under the same edge of the meridian from pole to pole have the same longitude.

The inhabitants of all places having the same longitude have noon and all the other hours of the day alike.

EXAMPLES. 1. What places have the same, or nearly the same, longitude as Stockholm?

Answer. Dantzic, Presburg, Tarento, the Cape of Good Hope, &c.

2. What places have the same longitude as Alexandria?

3. When it is ten o'clock in the evening at London, what inhabitants of the earth have the same hour?

4. What inhabitants of the earth have midnight when the inhabitants of Jamaica have midnight?

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* On maps the longitude is always placed at the top and bottom.

5. What places of the earth have the same longitude as the following places?

London
Pekin
Quebec
Dublin
The Sandwich Islands
Pelew Islands.

What places have the same longitude as the following?

6. Oporto
7. Cairo
8. Jerusalem
9. Botany Bay
10. Cape Horn
11. Ispahan.

PROBLEM V.

To find the latitude and longitude of any place.

RULE. Bring the given place to the brass meridian; the degree immediately above the place is the latitude, and the degree on the equator, cut by the brass meridian, is the longitude.

This problem is only an exercise of the *first* and *third.*

EXAMPLES. 1. What are the latitude and longitude of Petersburgh?

Answer. Latitude 60° N.; longitude $30\frac{1}{4}^\circ$ E.

2. Required the latitudes and longitudes of the following places:

Acapulco
Aleppo
Algiers
Archangel
Belfast
Bergen
Cusco
Copenhagen
Durazzo
Elsinore
Flushing
Cape Guardafui
Lima
Lizard
Lubec
Malacca
Manilla
Medina.

PROBLEM VI.

To find any place on the globe having the latitude and longitude of that place given.

RULE. Find the given longitude on the equator, and bring it to that part of the brass meridian marked 0, then under the given latitude on the brass meridian will be found the place required.

EXAMPLES. 1. What place has $151\frac{1}{2}^\circ$ east longitude and 34° south latitude?

Answer. Botany Bay.

What places have nearly the following latitudes and longitudes?

Latitudes.	Longitudes.	Latitudes.	Longitudes.
2. 50° N.	6° W.	12. 19½° N.	100 W.
3. 48¼ N.	16¼ E.	13. 60 N.	30¼ E.
4. 56 N.	3¼ W.	14. ¼ S.	78 W.
5. 52¼ N.	4¾ E.	15. 47 N.	70 W.
6. 31¼ N.	30 E.	16. 59¼ N.	18 E.
7. 64½ N.	39 E.	17. 8½ N.	81¼ E.
8. 34½ S.	18½ E.	18. 5 S.	119¾ E.
9. 3¾ S.	102¼ E.	19. 23 S.	42¾ W.
10. 34½ S.	58½ W.	20. 36 N.	5¼ W.
11. 32½ N.	52¾ E.	21. 32½ N.	17 W.

PROBLEM VII.

To find the difference of latitude between any two places.

RULE. Find the latitudes of both the places (by Prob. I.); then, if the latitudes be both north or both south, subtract the less from the greater, and the remainder will be the difference of latitude; but, if the latitudes be one north and the other south, add them together, and their sum will be the difference of latitude.

EXAMPLES. 1. What is the difference of latitude between Philadelphia and Petersburgh?

Petersburgh - - - - -	60 N.
Philadelphia - - - - -	40 N.
Difference	20

2. What is the difference of latitude between Madrid and Buenos Ayres?

Madrid - - - - - -	40 N.
Buenos Ayres - - - - -	35 S.
	75

Required the difference of latitude between the following places:

3. London and Rome
4. Delhi and Cape Comorin
5. Vera Cruz and Cape Horn
6. Mexico and Botany Bay
7. Astracan and Bombay
8. St. Helena and Manilla
9. Copenhagen and Toulon
10. Brest and Inverness
11. Cadiz and Sierra Leone
12. Alexandria and the Cape of Good Hope
13. Pekin and Lima
14. St. Salvador and Surinam
15. Washington and Quebec
16. Porto Bello and the Straits of Magellan
17. Trinidad I. and Trincomalé
18. Bencoolen and Calcutta.

19. What two places on the globe have the greatest difference of latitude?

PROBLEM VIII.

To find the difference of longitude between any two places.

RULE. Find the longitudes of both the places (by Prob. III.); then, if the longitudes be both east or both west, subtract the less longitude from the greater, and the remainder will be the difference of longitude: but, if the longitudes be one east and the other west, add them together, and their sum will be the difference of longitude, if it does not exceed 180 degrees.

When this sum exceeds 180 degrees, take it from 360, and the remainder will be the true difference of longitude.

EXAMPLES. 1. What is the difference of longitude between Barbadoes and Cape Verd?

Barbadoes	60 W.
Cape Verd	16¼ W.
	43¾

2. What is the difference of longitude between Buenos Ayres and the Cape of Good Hope?

Buenos Ayres	59 W.
Cape of Good Hope	18 E.
	77

3. What is the difference of longitude between Botany Bay and Owhyhee?

Botany Bay	151 E.
Owhyhee	156 W.
	307
	360
True Difference	53

Required the difference of longitude between the following places:

4. Vera Cruz and Canton
5. Bergen and Bombay
6. Columbo and Mexico
7. Juan Fernandez I. and Manilla
8. Pelew I. and Ispahan
9. Boston in America and Berlin
10. Constantinople and Batavia

11. Bermudas I. and I. of Rhodes
12. Portpatrick and Berne
13. Mount Hecla and Mount Vesuvius
14. Mount Ætna and Teneriffe
15. North Cape and Gibraltar.

16. What is the greatest difference of longitude comprehended between two places?

Problem IX.

To find the shortest distance between two places.

Rule. Lay the graduated edge of the quadrant of altitude over both places, so that the division marked 0 may be over one of them, and the degree over the other will show the number of degrees between them.

Multiply the degrees by 60, the product will be geographical miles; or multiply by 69½ for English miles.

Or, Take the distance between the two places with a pair of compasses, and apply that distance to the equator, which will show how many degrees it contains.

If the distance between the two places should exceed the length of the quadrant, stretch a piece of thread over the two places; the extent of thread between these marks, applied to the equator, from the meridian of London, will show the number of degrees between the two places.

Examples. 1. What is the nearest distance between the Lizard and the Island of Bermudas?

45¾ distance in degrees.
60
2700
30
15
745 geographical miles.

45·75 distance in degrees.
69·1
4575
41175
27450
3161·325 English miles.

2. What is the direct distance between London and Jamaica, in geographical and English miles?

3. What is the extent of Europe, in English miles, from Cape Matapan, in the Morea, to the North Cape, in Lapland?

4. What is the extent of Africa from Cape Verd to Cape Guardafui?

5. What is the extent of South America, from Cape Blanco ı the west to Cape St. Roque in the east?

6. Suppose the track of a ship to Madras be from the izard to St. Anthony, one of the Cape Verd Islands, thence St. Helena, thence to the Cape of Good Hope, thence to ıe east of the Mauritius, thence a little to the south-east of eylon, and thence to Madras; how many English miles is ıe Land's End from Madras?

What is the distance between the following places?

7. London and Paris
8. London and Cairo
9. Cairo and Bombay
10. London and Madeira
11. Madeira and the Cape of Good Hope
12. The Cape of Good Hope and Madras
13. Bristol and Oporto
14. Liverpool and New York.

15. How many miles English would a ship sail in circumıavigating the world by the following track?

London to Madeira
Madeira to Cape Horn
Cape Horn to Otaheite
Otaheite to Botany Bay
Botany Bay to Torres' Straits
Torres' Straits to the Cape of Good Hope
The Cape of Good Hope to St. Helena
St. Helena to the Azores
The Azores to London.

PROBLEM X.

place being given on the globe, to find all places which are situated at the same distance from it as any other given place.

RULE. Lay the graduated edge of the quadrant of altitude ver the two places, so that the division marked 0 may be ı one of the places, then observe what degree of the uadrant stands over the other place; move the quadrant ıtirely round, keeping the division marked 0 in its first tuation, and all places over which the observed degree ısses will be those sought.

OR, Place one foot of a pair of compasses in one of the ven places, and extend the other foot to the other given place; a circle described from the first place as a centre, with this extent, will pass through all the places sought.

If the distance between the two given places should exceed the length of the quadrant, or the extent of a pair of compasses, stretch a piece of thread over the two places, as in the preceding problem.

EXAMPLES. 1. It is required to find all the places on the globe which are situated at the same distance from London as Warsaw is.

Answer. Konigsburg, Buda, Posega, Alicant, &c.

2. What places are nearly at the same distance from London as Petersburgh is?

3. What places are nearly at the same distance from London as Constantinople is?

4 What places are nearly at the same distance from Rome as Madrid is?

What places are nearly at the same distance from London as the following places?

5. Rome
6. Moscow
7. New York
8. The Ferroe Isles
9. Oporto
10. Ispahan.

11. We procure a delicious fruit from an island in the Atlantic, at the same distance from London as Constantinople is, what are the island and the fruit?

PROBLEM XI.

Given the latitude of a place and its distance from a given place, to find that place whereof the latitude is given.

RULE. If the distance be given in English or geographical miles, turn them into degrees, by dividing by 69·1 for English miles, or 60 for geographical miles; then put that part of the graduated edge of the quadrant of altitude which is marked 0 upon the given place, and move the other end eastward or westward (according as the required place lies to the east or west of the given place), till the degrees of distance cut the given parallel of latitude: under the point of intersection you will find the place sought.

OR, Having reduced the miles into degrees, take the same number of degrees from the equator with a pair of compasses, and with one foot of the compasses in the given place, as a centre, and this extent of degrees, describe a circle on the globe; turn the globe till some point of this circle falls under

given latitude on the brass meridian, and the place
h coincides with this point of the circle is the place
ired.

AMPLES. 1. A place in latitude 60° N. is 1312·9 Eng-
miles from London, and it is situated in E. longitude ;
ired the place.

swer. Divide 1312·9 by 69·1 miles, the quotient will give 19 de-
; hence the required place is Petersburgh.

A place in latitude 32½° N. is 1350 geographical miles
London, and it is situated in W. longitude ; required the
.

swer. Divide 1350 by 60, the quotient is 22° 30′, or 22½ degrees ;
the required place is the west point of the island of Madeira.

What place in E. longitude, and 41° N. latitude, is
·2 English miles from London?

What place in W. longitude,and 13° N. latitude, is 3660
raphical miles from London ?

A place in E. longitude, and 30° N. latitude, is 31 de-
s from London, what is the place?

A place in E. longitude, and 60° N. latitude, is 19 de-
s from London, what is the place?

What place in 41° N. latitude, and E. longitude, is 22
ees from London?

What place in 18° S. latitude, and W. longitude, is 73
ees from Cape Horn?

What place in 19° N. latitude, and E. of Cairo, is 40 de-
s from that place?

PROBLEM XII.

*n the longitude of a place and its distance from a given
ace, to find that place whereof the longitude is given.*

ULE. If the distance be given in miles, turn them into
ees, as in the last problem. Bring the given longitude
e brass meridian. Place the 0 of the quadrant of alti-
over the given place, and move the other end of the
rant till the given number of degrees cut the brass
dian, under which point the required place will be
d.

he question will direct whether the quadrant is to be
to the north or south of the given place.

R, Having reduced the miles into degrees, take the same
ber of degrees from the equator with a pair of com-

passes, and with one foot of the compasses in th place, as a centre, and this extent of degrees, des circle on the globe; bring the given longitude to tl meridian, and you will find the place, upon the circl the brass meridian.

Examples. 1. A place in north latitude, and ir grees west longitude, is 4215·1 English miles from I required the place.

Answer. Divide 4215·1 miles by 69·1 miles, the quotient wi degrees; hence the required place is the island of Barbadoes.

2. A place in north latitude, and in 75¼ degre longitude, is 3120 geographical miles from Londor place is it?

3. A place in 31¼ degrees east longitude, and southward of London, is 2211·2 English miles from quired the place.

4. A place in 29 degrees east longitude, and southward of London, is 1520·2 English miles from quired the place.

5. A place in 18 degrees east longitude, and south Rio Janeiro, is 54½ degrees from it; required the pl

6. What place situated to the northward of Mad in 116⅓ east longitude, is 43 degrees from it?

7. What place in 68 degrees east longitude, and no of Ispahan, is 28 degrees from it?

8. What place in 18 degrees east longitude, and no of Moscow, is 10½ degrees from it?

Problem XIII.

To find how many miles make a degree of longitude given parallel of latitude.

Rule. Lay the quadrant of altitude parallel to th tor, between any two meridians in the given latitude differ in longitude 15 degrees*; the number of deg tercepted between them, multiplied by 4, will give th of a degree in geographical miles. The geographic may be brought into English miles by multiplying and dividing by 60.

---

* The meridians on Cary's *large* globes are drawn through degrees. The rule will answer for these globes by reading 1 for 15 degrees, and multiplying by 6 instead of 4.

Or, Take the distance between two meridians, which differ in longitude 15 degrees in the given parallel of latiude, with a pair of compasses; apply this distance to the equator, and observe how many degrees it makes: with which proceed as above.

Since the quadrant of altitude will measure no arc truly but that of a great circle; and a pair of compasses will only measure the chord of an arc, not the arc itself; it follows that the preceding rule cannot be mathematically true, though sufficiently correct for practical purposes. When great exactness is required, recourse must be had to calculation.

The above rule is founded on a supposition that the number of degrees contained between any two meridians, reckoned on the equator, is to the number of degrees contained between the same meridians, on any parallel of latitude, as the number of geographical miles contained in one degree of the equator, is to the number of geographical miles contained in one degree on the given parallel of latitude. Thus, in the latitude of London, wo places which differ 15 degrees in longitude are 9¼° distant by the rule. Hence, 15° : 9¼°::60m. : 37m., or 15° : 60m. :: 9¼° : 37m., but 15 is o 60 as 1 is to 4, therefore, 1 : 4 ::9¼ : 37 geographical miles contained n one degree. Now, any number of geographical miles (as before oberved) may be brought into English miles by multiplying by 69·1 and dividing by 60.

Examples. 1. How many geographical and English miles make a degree in the latitude of Pekin?

Answer. The latitude of Pekin is 40° north: the distance between two meridians in that latitude (which differ in longitude 15 degrees) is 11½ egrees. Now 11½ degrees multiplied by 4, produces 46 geographical miles for the length of a degree of longitude in the latitude of Pekin; and if 46 be multiplied by 69·1 and the product divided 60, it will give 2·97, or nearly 53 for the length of a degree in English miles. Or, by he rule of three, 15° : 69·1m. ::11½° : 52·97 miles.

2. How many miles make a degree in the parallels of latitude wherein the following places are situated?

Surinam
Barbadoes
Havannah
Bermudas I.
Washington
Quebec
Skalholt
North Cape
Spitzbergen
Cape Verd
Alexandria
Paris.

The following table is calculated thus: — Radius is to the length of a degree upon the equator, as the co-sine of the given latitude is to the length of a degree in that latitude. See this proposition illustrated in *Keith's Trigonometry*, page 296. fourth edition.

Deg. Lat.	Geog. Miles.	English Miles.	Deg. Lat.	Geog. Miles.	English Miles.	Deg. Lat.	Geog. Miles.	English Miles.
0	60·00	69·07	31	51·43	59·13	61	29·09	33·45
1	59·99	69·06	32	50·88	58·51	62	28·17	32·40
2	59·96	69·03	33	50·32	57·87	63	27·24	31·33
3	59·92	68·97	34	49·74	57·20	64	26·30	30·24
4	59·85	68·90	35	49·15	56·51	65	25·36	29·15
5	59·77	68·81	36	48·54	55·81	66	24·40	28·06
6	59·67	68·62	37	47·92	55·10	67	23·45	26·96
7	59·55	68·48	38	47·28	54·37	68	22·48	25·85
8	59·42	68·31	39	46·63	53·62	69	21·50	24·73
9	59·26	68·15	40	45·96	52·85	70	20·52	23·60
10	59·09	67·95	41	45·28	52·07	71	19·53	22·47
11	58·89	67·73	42	44·59	51·27	72	18·54	21·32
12	58·69	67·48	43	43·88	50·46	73	17·54	20·17
13	58·46	67·21	44	43·16	49·63	74	16·54	19·02
14	58·22	66·95	45	42·43	48·78	75	15·53	17·86
15	57·95	66·65	46	41·68	47·93	76	14·52	16·70
16	57·67	66·31	47	40·92	47·06	77	13·50	15·52
17	57·38	65·98	48	40·15	46·16	78	12·48	14·35
18	57·06	65·62	49	39·36	45·26	79	11·45	13·17
19	56·73	65·24	50	38·57	44·35	80	10·42	11·98
20	56·38	64·84	51	37·76	43·42	81	9·38	10·79
21	56·01	64·42	52	36·94	42·48	82	8·35	9·59
22	55·63	63·97	53	36·11	41·53	83	7·31	8·41
23	55·23	63·51	54	35·27	40·56	84	6·27	7·21
24	54·81	63·03	55	34·41	39·58	85	5·22	6·00
25	54·38	62·53	56	33·53	38·58	86	4·18	4·81
26	53·93	62·02	57	32·68	37·58	87	3·14	3·61
27	53·46	61·48	58	31·79	36·57	88	2·09	2·41
28	52·97	60·93	59	30 90	35·54	89	1·05	1·21
29	52·48	60·35	60	30·00	34·50	90	0·00	0·00
30	51·96	59·75	Length of a degree 69·07 English miles.					

PROBLEM XIV.

To find the bearing of one place from another.

RULE. If both the places be situated on the same parallel of latitude, their bearing is either east or west from each other; if they be situated on the same meridian, they bear north and south from each other.

If not in the above positions, make a small mariner's com-ss (*such as in Plate* I. *Fig.* 4.), and apply the centre of it any given place, so that the north and south points may incide with some meridian; the other points will show the arings of all the circumjacent places, to the distance of wards of a thousand miles, if the central place be not far stant from the equator.

Examples. 1. Which way must a ship steer from the izard to the island of Bermudas?

Answer. W.S.W.

2. Which way must a ship steer from the Lizard to the land of Madeira.

Answer. S.S.W.

3. Required the bearing between London and the following laces:

Amsterdam
Athens
Bergen
Berlin
Berne
Brussels
Buda
Copenhagen
Dublin
Edinburgh
Lisbon
Madrid
Naples
Paris
Petersburgh
Prague
Rome
Stockholm
Vienna
Warsaw.

PROBLEM XV.

To find the angle of position between two places.

Rule. Elevate the pole equal to the latitude of one of e given places; bring that place to the brass meridian, d screw the quadrant of altitude over it; next move the adrant till its graduated edge falls upon the other place; en the number of degrees on the wooden horizon, between e graduated edge of the quadrant and the brass meridian, ckoning towards the elevated pole, is the angle of position tween the two places.

Examples. 1. What is the angle of position between ondon and Prague?

Answer. 90 degrees from the north towards the east: the quadrant of itude will fall upon the east point of the horizon, and pass over or near e following places, viz. Rotterdam, Frankfort, Cracow, Ockzakov, ffa, south part of the Caspian Sea, Guzerat in India, Madras, and part the island of Ceylon. Hence all these places have the same angle of sition from London.

2. What is the angle of position between London and Port Royal in Jamaica?

Answer. 90 degrees from the north towards the west; the quadrant of altitude will fall upon the west point of the horizon.

3. What is the angle of position between Philadelphia and Madrid?

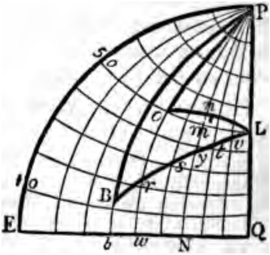
Answer. 65 degrees from the north towards the east; the quadrant of altitude will fall between the E.N.E. and N.E. by E. points of the horizon.

4. Required the angles of position between London and the following places:

Amsterdam
Berlin
Berne
Constantinople
Copenhagen
Cairo
Lisbon
Madras
Rome
Stockholm
Petersburgh
Quebec.

The preceding problem has been the occasion of many disputes among writers on the globes. Some suppose the angle of position to represent the true bearing of two places, viz. *that point of the compass upon which any person must constantly sail or travel, from the one place to the other;* while others contend that the angle of position between two places is very different from their bearing by the mariner's compass. We shall here endeavour to set the matter in a clear point of view. The following figure represents a quarter of the sphere, stereographically projected on the plane of the meridian with the half meridians and parallels of latitude drawn through every ten degrees; P represents the north pole, and E Q a portion of the equator. Now, by attending to the manner of finding the angle of position, as laid down in the foregoing problem, we shall find that the *quadrant of altitude always forms the base of a spherical triangle, the two sides of which triangle are the complements of the latitudes of the two places, and the vertical angle is their difference of longitude.* The angles at the base of this triangle are the angles of position between the two places.

1. *When the two places are situated on the same parallel of latitude.*



Let two places L and O be situated in latitude 50° north, and differing in longitude 48° 50′, which will nearly correspond with the Land's End and the eastern coast of Newfoundland (*see the note to Prob.* IX); then O P and L P will be each 40 degrees, the angle O P L, measured by the arc *w* Q, will be 48° 50′; whence the arc of nearest distance O *n* L may be found (by Case III. page 245, *Keith's Trigonometry*) being 30° 39′ 6″, the angle P L O equal to P O L, the triangle being isosceles, is 70° 49′ 30″; and if *n* be the middle point between L and O, the latitude of that point will be found to be 52° 37′ north, and the angles P *n* L and P *n* O will be right angles. Now, if an indefinite number of points be taken along the edge of the quadrant of altitude, viz. on the arc L *n* O, the angle of position between L and each of these points will be N. 70° 49′ 30″ W.; but, if it were possible for a ship to sail along the arc L *n* O, by the compass, her latitude would gradually increase between L and *n*, from 50° N. to 52° 37′ N.; and the courses she must steer would vary from 70° 49′ 30″ at L, to 90° at *n*. In sailing from *n* to O, she must decrease her latitude from 52° 37′ N. to 50° N. and her courses must vary from 90°, or directly west, to 70° 49′ 30″; but, if a ship were to sail along the parallel of latitude L *m* O, her course would be invariably due west. Hence it follows that, if two places be situated on the same parallel of latitude, the angle of position between them cannot represent their true bearing by the mariner's compass.

COROLLARY. If the two places were situated on the equator as at *w* and Q, the angle of position between Q and *w* and between Q and all the intermediate points, as at N, would be 90 degrees. In this case therefore, and in this *only*, the angle of position shows the true bearing by the compass.

2. *If the two places differ both in latitudes and longitudes.*

Let L represent a place in latitude 50° N.; B a place in latitude 13° 30′ N., and let their difference of longitude B P L, measured by the arc *b* Q, be 52° 58′. The angle of position between L and B (calculated by spherical trigonometry) will be found to be S. 68° 57′ W. and the angle of position between B and L will be N. 38° 5′ E., whereas the direct course by the compass from L to B (calculated by *Mercator's Sailing*) is S. 50° 6′ W., and from B to L it is N. 50° 6′ E. If we assume any number of points on the arc L B, the angle of position between L and each of these points will be invariable; viz. P L *v*, P L *t*, P L *y*, P L *s*, P L *r*, &c. are each equal to 68° 57′: while the angle of position between each of these places and L, viz. P *v* L, P *t* L, P *y* L, P *s* L, P *r* L, &c. is continually diminishing. If a ship, therefore, were to sail from L, on a S. 68° 57′ W. course by the mariner's compass, she would never arrive at B; and were she to sail from B, on a N. 38° 5′ E. course by the compass, she would never arrive at L.

Hence an angle of position between two places cannot represent their bearing, except those places be on the equator, or upon the same meridian.

PROBLEM XVI.

To find the Antœci, Periœci, and Antipodes to the inhabitants of any place.

RULE. Place the two poles of the globe in the horizon, and bring the given place to the eastern part of the horizon; then if the given place be in north latitude, observe how many degrees it is to the northward of the east point of the horizon; the same number of degrees to the southward of the east point will show the Antœci; an equal number of degrees, counted from the west point of the horizon towards the north, will show the Periœci; and the same number of degrees, counted towards the south of the west, will point out the Antipodes. If the place be in south latitude, the same rule will serve by reading south for north, and the contrary.

OR THUS:

For the Antœci. Bring the given place to the brass meridian and observe its latitude, then in the opposite hemisphere, under the same degree of latitude, you will find the Antœci.

For the Periœci. Bring the given place to the brass meridian, and set the index of the hour circle to 12, turn the globe half round, or till the index points to the other 12, then under the latitude of the given place you will find the Periœci.

For the Antipodes. Bring the given place to the brass meridian, and set the index of the hour circle to 12, turn the globe half round, or till the index points to the other 12, then under the same degree of latitude with the given place, but in the opposite hemisphere, you will find the Antipodes.

EXAMPLES. 1. Required the Antœci, Periœci, and Antipodes, to the inhabitants of the island of Bermudas.

Answer. Their Antœci are situated in Paraguay, a little N.W. of Buenos Ayres; their Periœci in China, N.W. of Nankin; and their Antipodes in the S.W. part of New Holland.

2. Required the Antœci, Periœci, and Antipodes, to the inhabitants of the Cape of Good Hope.

3. Captain Cook, in one of his voyages, was in 50 degrees south latitude, and 180 degrees of longitude; in what part of Europe were his Antipodes?

4. Required the Antœci to the inhabitants of the Falkland Islands.

5. Required the Periœci to the inhabitants of the Philippine Islands.

6. What inhabitants of the earth are Antipodes to those of Buenos Ayres?

What places have their inhabitants the Antœci to the following places?

7. St. Helena
8. Isle of France
9. Philippine Islands
10. Cape Horn
11. St. Domingo
12. Juan Fernandez.
13. Otaheite
14. Truxillo
15. Quebec.

Required the Periœci of the following places:

16. New Caledonia
17. The Society Isles
18. The Sandwich Isles
19. The Marquesas Isles
20. Quebec
21. New Orleans
22. Pekin
23. Canton
24. Celebes Isles.

Required the places whose inhabitants are Antipodes to those of the following places:

25. The Azores
26. Cape Horn
27. Borneo
28. New Zealand
29. Lima
30. New Caledonia
31. Kerguelen's Land
32. Monte Video
33. London.

PROBLEM XVII.

To find at what rate per hour *the inhabitants of any given place are carried, from west to east, by the revolution of the earth on its axis.*

RULE. Find how many miles make a degree of longitude in the latitude of the given place (by Problem XIII.), which multiply by 15 for the answer.*

OR, Look for the latitude of the given place in the table, Problem XIII., against which you will find the number of miles contained in one degree; multiply these miles by 15, and reject two figures from the right hand of the product for decimals; the result will be the answer.

EXAMPLES. 1. At what rate *per* hour are the inhabitants of Madrid carried from west to east by the revolution of the earth on its axis?

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* The reason of this rule is obvious, for if m be the number of miles contained in a degree, we have 24 hours : $360^\circ \times m$ :: 1 hour : the answer; but, 24 is contained 15 times in 360; therefore 1 hour : $15 \times m$ :: 1 hour : the answer; that is, on a supposition that the earth turns on its axis from west to east in 24 hours; but we have before observed that it turns on its axis in 23 hours 56 min. 4 sec., which will make a small difference not worth notice.

Answer. The latitude of Madrid is about 40° N. where a degree of longitude measures 46 geographical, or 53 English miles (see Example 1. Prob. XIII.) Now, 46 multiplied by 15 produces 690; and 53 multiplied by 15 produces 795; hence the inhabitants of Madrid are carried 690 geographical, or 795 English miles *per hour.*

By the Table. Against the latitude 40 you will find 45·96 geographical miles, and 52·85 English miles: Hence,
45·96 × 15 = 689·40 and 52·85 × 15 = 792·75: by rejecting the two right-hand figures from each product, the result will be 689 geographical miles, and 792 English miles, agreeing nearly with the above.

At what rate *per* hour are the inhabitants of the following places carried from west to east by the revolution of the earth on its axis?

2. Skalholt
3. Spitzbergen
4. Petersburgh
5. London
6. Philadelphia
7. Cairo
8. Barbadoes
9. Quito
10. Cape of Good Hope
11. Calcutta
12. Delhi
13. Batavia.

PROBLEM XVIII.

A particular place, and the hour of the day at that place, being given, to find what hour it is at any other place.

RULE. Bring the place at which the time is given to the brass meridian, and set the index to the given hour; turn the globe till the other place comes to the meridian, and the index will show the required time.*

OR, WITHOUT THE HOUR-CIRCLE.

Find the difference of longitude between the two places (by Problem VIII.), and turn it into time by dividing the degrees by 15; the quotient is hours, and the remainder multiplied by 4 gives minutes. If the place at which the time is required be to the eastward of the other place, the clocks are faster, and this difference of time must be added; but if to the westward, it must be subtracted to find the time at the required place.

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* While turning the globe it will be desirable to observe the hours on the index as they pass under the meridian, to ascertain if the hour found be in the morning or evening; as when the XII passes under the meridian, the hours change from morning to evening, or the contrary.

If, in subtracting, the difference of time is greater than the given time, add 12 to the hours in the upper line, and change the name from morning to evening, or the contrary; and if, in adding, the sum is more than 12, subtract 12, and change the name as above.

If the globe have two rows of figures on the hour circle, that row must be used which is numbered from west to east; this is generally the outermost row.

EXAMPLES. 1. When it is ten o'clock in the morning at London, what hour is it at Petersburg?

Answer. Twelve o'clock at noon.

OR, The difference of longitude between Petersburg and London is 30° 25′, which multiplied by 4 produces 2 hours 1 min. 40 sec., the difference of time shown by the clocks of London and Petersburg: hence as Petersburg lies to the east of London, when it is ten o'clock in the morning at London, it is one minute and forty seconds past twelve at Petersburg.

2. When it is two o'clock in the afternoon at Alexandria in Egypt, what hour is it at Philadelphia?

Answer. Seven o'clock in the morning.

Or,	The longitude of Alexandria is	30°	16′	E.
	The longitude of Philadelphia is	75	19	W.
	Difference of longitude	105	35	
			4	

Difference of longitude in time 7 h. 2 m. 20 sec., the clocks at Philadelphia are slower than those of Alexandria: hence when it is two o'clock in the afternoon at Alexandria, it is 57 m. 40 sec. past six in the morning at Philadelphia.

3. When it is noon at London, what hour is it at Calcutta?

4. When it is ten o'clock in the morning at London, what hour is it at Washington?

5. When it is nine o'clock in the morning at Jamaica, what o'clock is it at Madras?

6. My watch was well regulated at London, and when I arrived at Madras, which was after a five months' voyage, it was four hours and fifty minutes slower than the clocks there. Had it gained or lost during the voyage? and how much?

7. When it is 6 P.M. at Liverpool, what is the hour at Montreal and Mexico?

8. What is the time at Bombay and Siam when it is 4 A.M. at Cairo?

9. When it is 9 P.M. at Rhodes, what is the hour at Surinam and Manilla?

10. When it is 5 A.M. at Glasgow, what time is it at Acapulco and Owhyhee?

11. When it is noon at Aberdeen, what is the hour at Cracow and Smyrna?

12. When it is 5 P.M. at Lima, what is the hour at Otaheite?

13. What o'clock is it at Jerusalem when it is 5' P.M. at Surat?

14. What hour are the clocks at St. Petersburg striking when St. Paul's at London is striking 12 at noon?

15. Regulated my watch on leaving London by St. Paul's, and on arriving at Jamaica it was 4 hours and 30 minutes faster than the clocks there. Had it gained or lost?

16. Regulated my watch by the clocks at Calcutta, and on arriving at the Cape of Good Hope found it 4 hours and 40 minutes faster than the clocks there. Was mine a good watch?

17. Regulated my watch by the clocks at New York, and on arriving at Liverpool found it was 5 hours and a quarter slower than the clocks there. Had it gained or lost? and how much?

PROBLEM XIX.

A particular place and the hour of the day being given, to find all places on the globe where it is then noon, or any other proposed hour.

RULE. Bring the given place to the brass meridian, and set the index to the given hour; turn the globe till the index points to 12 at noon, or to the hour proposed, then the places required will be found under the brass meridian.

OR, WITHOUT THE HOUR-CIRCLE.

Reduce the difference of time between the given place and the required places into minutes; these minutes, divided by 4, will give degrees of longitude; if there be a remainder after dividing by 4, multiply it by 15; the product will be minutes or miles of longitude. The difference of longitude between the given place and the required places being thus determined, if the hour at the required places be earlier than he hour at the given place, the required places lie so many degrees to the westward of the given place as are equal to he difference of longitude; if the hour at the required places be later than the hour at the given place, the required places lie so many degrees to the eastward of the given place as are qual to the difference of longitude.

Examples. 1. When it is noon at London, at what places s it half-past eight o'clock in the morning?

Answer. The eastern coast of Newfoundland, Cayenne, part of Paraguay, &c.

Or, The difference of time between London, the given place, and the equired places, is 3 hours 30 min.

3 h. 30 m.
60
4)210 m.
52° — 2′
60
4)120
30′

The difference of longitude between the given place and the required places is 52° 30′. The hour at the required places being earlier than that at the given place, they lie 52° 30′ westward of the given place. Hence, all places situated in 52° 30′ west longitude from London are the places sought, and will be found to be Cayenne, &c. as above.

2. When it is two o'clock in the afternoon at London, at what places is it ½ past five in the afternoon?

Answer. The Caspian Sea, western part of Nova Zembla; the Island f Socotra, eastern part of Madagascar, &c.

3. When it is ¾ past four in the afternoon at Paris, where s it noon?

4. When it is ¾ past seven in the morning at Ispahan, where is it noon?

5. When it is noon at Madras, where is it ½ past six o'clock n the morning?

6. At sea in latitude 40° north, when it was ten o'clock in the morning by the time-piece, which shows the hour at London, it was exactly nine o'clock in the morning at the ship, by a correct celestial observation. In what part of the ocean was the ship?

7. When it is noon at London, what inhabitants of the earth have midnight?

8. When it is ten o'clock in the morning at London, where s it ten o'clock in the evening?

9. When it is 7 A.M. at Lima, where is it 4 P.M.?

10. When it is 3 P.M. at Ispahan, where is it noon?

11. To what places is it 5 P.M. when it is 1 P.M. at Rome?

12. To what three large cities is it noon when it is 10 A.M. at London?

13. To what large city is it 6 P.M. when it is 6 minutes past noon at London?

14. What places have their clocks 10 P.M. when it is noon at London?

15. To what large city in 40° north latitude is it 8 P.M. when it is noon at Madrid?

PROBLEM XX.

To find the sun's longitude (commonly called the sun's place in the ecliptic), and his declination.

RULE. Look for the given day in the circle of months on the horizon, against which, in the circle of signs, are the sign and degree in which the sun is for that day. Find the same sign and degree in the ecliptic on the surface of the globe; bring the degree of the ecliptic, thus found, to the brass meridian; the degree over it is the sun's declination.

This problem may be performed by the celestial globe, using the same rule.

OR, BY THE ANALEMMA.*

Bring the analemma to the brass meridian, and the degree on the brass meridian, exactly above the day of the month, is the sun's declination. Turn the globe till a point of the ecliptic, corresponding to the day of the month, passes under the degree of the sun's declination; that point will be the sun's longitude or place for the given day. If the sun's declination be *north*, and increasing, the sun's longitude will be somewhere between Aries and Cancer. If the declination be decreasing, the longitude will be between Cancer and Libra. If the sun's declination be *south*, and increasing, the sun's longitude will be between Libra and Capricorn; if the declination be decreasing, the longitude will be between Capricorn and Aries.

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* The Analemma is properly an orthographic projection of the sphere on the plane of the meridian; but what is called the Analemma on the globe is a narrow slip of paper, the length of which is equal to the breadth of the torrid zone. It is pasted on some vacant place on the globe in the torrid zone, and is divided into months, and days of the months, corresponding to the sun's declination for every day in the year. It is divided into two parts; the right-hand part begins at the winter solstice, or December 21st, and is reckoned upwards towards the summer solstice, or June 21st, where the left-hand part begins, which is reckoned downwards in a similar manner, or towards the winter solstice. On CARY's globes the Analemma somewhat resembles the figure 8. It appears to have been drawn in this shape for the convenience of showing the equation of time, by means of a straight line which passes through the middle of it. The equation of time is placed on the horizon of BARDIN's and NEWTON's globes.

The sun's longitude is given in the *third* page and declination in the *second* page of every month in the *Nautical Almanac*, for every day in that month; they are likewise given in *White's Ephemeris* for every day in the year.

EXAMPLES. 1. What is the sun's longitude and declination on the 15th of May, 1844?

Answer. The sun's longitude is 54° 42′ or 24° 42′ in ♉, and declination 18° 57′.

2. Required the sun's place and declination for the following days.

January 21.
February 7.
March 16.
April 8.
May 18.
June 11.
July 11.
August 1.
September 9.
October 16.
November 17.
December 1.

THE SUN'S DECLINATION.

Day.	January.	February.	March.	April.	May.	June.
	South.	South.	South.	North.	North.	North.
	° ′	° ′	° ′	° ′	° ′	° ′
1	23 2	17 9	7 39	4 28	15 0	22 2
2	22 57	16 52	7 16	4 51	15 18	22 10
3	22 51	16 34	6 53	5 14	15 36	22 17
4	22 45	16 17	6 30	5 37	15 54	22 25
5	22 39	15 58	6 7	5 59	16 11	22 32
6	22 32	15 40	5 44	6 22	16 28	22 38
7	22 24	15 22	5 22	6 45	16 45	22 44
8	22 16	15 3	4 58	7 7	17 1	22 50
9	22 8	14 44	4 34	7 30	17 18	22 55
10	22 0	14 24	4 11	7 52	17 34	23 0
11	21 50	14 5	3 47	8 14	17 49	23 5
12	21 41	13 45	3 24	8 36	18 4	23 9
13	21 31	13 25	3 0	8 58	18 20	23 13
14	21 21	13 5	2 36	9 20	18 34	23 16
15	21 10	12 44	2 13	9 41	18 49	23 19
16	20 59	12 23	1 49	10 2	19 3	23 21
17	20 47	12 3	1 25	10 24	19 17	23 23
18	20 35	12 42	1 2	10 45	19 30	23 25
19	20 23	11 20	0 38	11 6	19 43	23 26
20	20 10	10 59	0 14	11 26	19 56	23 27
21	19 57	10 37	N 9	11 47	20 8	23 28
22	19 43	10 16	33	12 7	20 20	23 28
23	19 29	9 54	57	12 27	20 32	23 28
24	19 15	9 32	1 20	12 47	20 44	23 26
25	19 0	9 9	1 44	13 7	20 55	23 25
26	18 46	8 47	2 7	13 26	21 5	23 23
27	18 30	8 25	2 31	13 46	21 16	23 21
28	18 15	8 2	2 54	14 5	21 26	23 19
29	17 59	—	3 18	14 23	21 35	23 16
30	17 42	—	3 41	14 42	21 44	23 13
31	17 25	—	4 4	—	21 53	—

THE SUN'S DECLINATION.

Day.	July.	August.	Sept.	October.	Nov.	Dec.
	North.	North.	North.	South.	South.	South.
	° ′	° ′	° ′	° ′	° ′	° ′
1	23 9	18 7	8 24	3 5	14 22	21 48
2	23 5	17 51	8 2	3 29	14 41	21 57
3	23 0	17 36	7 40	3 52	15 0	22 6
4	22 55	17 20	7 18	4 15	15 19	22 14
5	22 50	17 4	6 56	4 38	15 38	22 22
6	22 44	16 48	6 33	5 1	15 56	22 29
7	22 38	16 31	6 11	5 24	16 14	22 36
8	22 32	16 15	5 48	5 47	16 31	22 43
9	22 25	15 57	5 26	6 10	16 19	22 49
10	22 18	15 40	5 3	6 33	17 6	22 55
11	22 10	15 22	4 40	6 56	17 23	23 0
12	22 2	15 5	4 17	7 19	17 39	23 5
13	21 54	14 46	3 54	7 41	17 55	23 9
14	21 45	14 28	3 31	8 4	18 11	23 13
15	21 36	14 10	3 8	8 26	18 27	23 16
16	21 26	13 51	2 45	8 48	18 42	23 20
17	21 16	13 32	2 22	9 10	18 57	23 22
18	21 6	13 12	1 59	9 32	19 12	23 24
19	20 55	12 53	1 35	9 54	19 26	23 26
20	20 44	12 33	1 12	10 16	19 40	23 27
21	20 33	12 13	49	10 37	19 53	23 28
22	20 21	11 53	25	10 59	20 6	23 28
23	20 9	11 33	2	11 20	20 19	23 27
24	19 57	11 13	S 22	11 41	20 32	23 26
25	19 44	10 52	45	12 2	20 44	23 25
26	19 31	10 31	1 8	12 23	20 55	23 23
27	19 18	10 11	1 32	12 43	21 7	23 21
28	19 4	9 49	1 55	13 3	21 17	23 18
29	18 50	9 28	2 19	13 23	21 28	23 15
30	18 36	9 7	2 42	13 43	21 38	23 12
31	18 22	8 45	—	14 3	—	23 8

PROBLEM XXI.

To place the globe in the same situation WITH RESP THE SUN, *as our earth is at the* EQUINOXES, SUMMER SOLSTICE, *and at the* WINTER SOLSTIC *thereby to show the comparative lengths of the and shortest days.*[*]

I. FOR THE EQUINOXES.—Place the two poles globe in the horizon: for at this time the sun has no tion, being in the equinoctial in the heavens, whic imaginary line standing vertically over the equator earth. Now, if we suppose the sun to be fixed, at a derable distance from the globe, vertically over that the brass meridian which is marked 0, it is evident wooden horizon will be the boundary of light and d on the globe, and that the upper hemisphere will be ened from pole to pole.

Meridians, or lines of longitude, being generally dr the globe through every 15 degrees of the equator, will *apparently* pass from one meridian to anothe hour. If you bring the point Aries on the equato eastern part of the horizon, the point Libra will be western part thereof; and the sun will appear to be to the inhabitants of London† and to all places un same meridian: let the globe be now turned gentl axis towards the east, the sun will appear to move the west, and, as the different places successively e dark hemisphere, the sun will appear to be setting west. Continue the motion of the globe eastward, till comes to the western edge of the horizon; the mo emerges above the horizon, the sun will appear to b in the east. If the motion of the globe on its axis be continued eastward, the sun will appear to rise higher and higher, and to move towards the west; when London comes to the brass meridian, the sun will appear at its greatest height; and after London has passed the brass meridian, he will continue his apparent motion westward, and gradually diminish in altitude till London comes to the eastern part of the horizon, when he will again be setting. During this revolution of the earth on its axis, every place on its surface has been twelve hours in the dark hemisphere, and twelve hours in the enlightened hemisphere; consequently the days and nights are equal all over the world; for all the parallels of latitude are divided into two equal parts by the horizon, and in every degree of latitude there are six meridians between the eastern part of the horizon and the brass meridian; each of these meridians answers to one hour, hence half the length of the day is six hours, and the whole length twelve hours.

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[*] In this problem, as in all others where the pole is elevat sun's declination, the sun is supposed to be fixed, and the earth on its axis from west to east. The author of this work has a li ball made to represent the sun; this ball is fixed upon a str and when used, slides out of a socket like an achromatic telescop socket is made to screw to the brass meridian (of any globe) sun's declination, and the little brass ball representing the su over the declination, at a considerable distance from the globe.

† The meridian of London is here supposed to pass through noctial point Aries, as on the best modern globes.

If any place be brought to the brass meridian, the number of degrees between that place and the horizon (reckoned the nearest way) will be the sun's meridian altitude. Thus, if London be brought to the meridian, the sun will then appear exactly south, and its altitude will be 38½ degrees; the sun's meridian altitude at Philadelphia will be 50 degrees; his meridian altitude at Quito 90 degrees; and here, as in every place on the equator, as the globe turns on its axis, the sun will be vertical. At the Cape of Good Hope the sun will appear due north at noon, and his altitude will be 55½ degrees.

II. FOR THE SUMMER SOLSTICE.—The summer solstice, to the inhabitants of north latitude, happens on the 21st of June, when the sun enters Cancer, at which time his declination is 23° 28′ north. Elevate the north pole 23½ degrees above the northern point of the horizon, bring the sign of Cancer in the ecliptic to the brass meridian, and over that degree of the brass meridian under which this sign stands, let the sun be supposed to be fixed at a considerable distance from the globe.

While the globe remains in this position, it will be seen that the equator is exactly divided into two equal parts, the equinoctial point Aries being in the western part of the horizon, and the opposite point Libra in the eastern part, and between the horizon and the brass meridian (counting on the

ator) there are six meridians, each fifteen degrees, or an
r apart; consequently the day at the equator is 12 hours
g. From the equator northward as far as the arctic circle,
diurnal arcs will exceed the *nocturnal arcs;* that is,
re than one-half of any of the parallels of latitude will be
ve the horizon, and of course less than one-half will be
ow, so that the days are longer than the nights. All the
allels of latitude within the Arctic circle will be wholly
ve the horizon, consequently those inhabitants will have
night. From the equator southward, as far as the Ant-
tic circle, the *nocturnal arcs* will exceed the *diurnal*
s; that is, more than one-half of any one of the parallels
latitude will be below the horizon, and consequently less
n one-half will be above. All the parallels of latitude
hin the Antarctic circle will be wholly below the horizon,
the inhabitants, if any, will have twilight or dark night.

rom a little attention to the parallels of latitude, while
globe remains in this position, it will easily be seen that
arcs of those parallels which are above the horizon north
he equator, are exactly of the same length as those below
horizon, south of the equator; consequently, when the
abitants of north latitude have the longest day, those in
th latitude have the longest night. It will likewise appear,
t the arcs of those parallels which are above the horizon,
th of the equator, are exactly of the same length as those
ow the horizon north of the equator; therefore, when the
abitants who are situated south of the equator have the
rtest day, those who live north of the equator have the
rtest night.

y counting the number of meridians, (supposing them
e drawn through every fifteen degrees of the equator,)
ween the horizon and the brass meridian, on any parallel
atitude, half the length of the day will be determined in
t latitude, the double of which is the length of the day.

. In the parallel of 20 degrees north latitude, there are
meridians and two-thirds more, hence the longest day is
hours and 20 minutes; and in the parallel of 20 de-
es south latitude there are five meridians and one-third,
ce the shortest day in that latitude is 10 hours and 40
utes.

. In the parallel of 30 degrees north latitude, there are
en meridians between the horizon and the brass meridian,
ce the longest day is 14 hours; and in the same degree

of south latitude there are only five meridians, hence the shortest day in that latitude is 10 hours.

3. In the parallel of 50 degrees north latitude there are eight meridians between the horizon and the brass meridian; the longest day is therefore 16 hours; and in the same degree of south latitude there are only four meridians; hence the shortest day is 8 hours.

4. In the parallel of 60 degrees north latitude, there are 9¼ meridians from the horizon to the brass meridian, hence the longest day is 18½ hours; and in the same degree of south latitude, there are only 2¾ meridians; the length of the shortest day is therefore 5½ hours.

By turning the globe gently round on its axis from west to east, we shall readily perceive that the sun will be vertical to all the inhabitants under the tropic of Cancer, as the places successively pass the brass meridian.

If any place be brought to the brass meridian, the number of degrees between that place and the horizon (reckoned the nearest way) will show the sun's meridian altitude. Thus, at London, the sun's meridian altitude will be found to be about 62 degrees; at Petersburg, 54½ degrees; at Madrid, 73 degrees, &c. To the inhabitants of these places the sun appears due south at noon. At Madras the sun's meridian altitude will be 79½ degrees; at the Cape of Good Hope, 32 degrees; at Cape Horn, 10½ degrees, &c. The sun will appear due north to the inhabitants of these places at noon. If the southern extremity of Spitzbergen, in latitude 76½ north, be brought to that part of the brass meridian which is numbered from the equator towards the poles, the sun's meridian altitude will be 37 degrees, which is its greatest altitude; and if the globe be turned eastwards twelve hours, or till Spitzbergen comes to that part of the brass meridian which is numbered from the pole towards the equator, the sun's altitude will be 10 degrees, which is its least altitude for the day given in the problem. It was shown, in the foregoing part of the problem, that, when the sun is vertically over the equator in the vernal equinox, the north pole begins to be enlightened; consequently the further the sun apparently proceeds in its course northward, the more day-light will be diffused over the north polar regions, and the sun will appear gradually to increase in altitude at the north pole, till the 21st of June, when his greatest height is 23½ degrees; he will then gradually diminish in height till the 23rd of September, the time of the autumnal equinox, when he will leave the north pole, and proceed towards the south; consequently the sun has been visible at the north pole for six months.

III. FOR THE WINTER SOLSTICE.—The winter solstice, to the inhabitants of north latitude, happens on the 21st of December, when the sun enters Capricorn, at which time his declination is 23° 28′ south. Elevate the south pole 23½ degrees above the southern point of the horizon, bring the sign of Capricorn in the ecliptic to the brass meridian, and over that degree of the brass meridian under which this sign stands, let the sun be supposed to be fixed at a considerable distance from the globe.

Here, as at the summer solstice, the days at the equator will be 12 hours long, but the equinoctial point Aries will be in the eastern part of the horizon, and Libra in the western. From the equator southward, as far as the Antarctic circle, the *diurnal arcs* will exceed the *nocturnal arcs*. All the parallels of latitude within the Antarctic circle will be wholly above the horizon. From the equator northward, the *nocturnal arcs* will exceed the *diurnal arcs*. All the parallels of latitude within the Arctic circle will be wholly below the horizon. The inhabitants south of the equator will now have their longest day, while those on the north of the equator will have their shortest day.

As the globe turns on its axis from west to east, the sun will be vertical successively to all the inhabitants under the tropic of Capricorn. By bringing any place to the brass meridian, and finding the sun's meridian altitude (as in the foregoing part of the problem), the greatest altitudes will be in south latitude, and the least in the north; contrary to what they were before. Thus, at London, the sun's greatest altitude will be only 15 degrees, instead of 62; and its greatest altitude at Cape Horn will now be 57½ degrees, instead of 10½, as at the summer solstice; hence it appears, that the difference between the sun's greatest and least meridian altitude at any place in the temperate zone, is equal to the breadth of the torrid zone, viz. 47 degrees, or more correctly 46° 56′. On the 23rd of September, when the sun enters Libra, that is, at the time of the autumnal equinox, the south pole begins to be enlightened, and, as the sun's declination increases southward, he will shine further over the south pole, and gradually increase in altitude at the pole; for, at all times, his altitude at either pole is equal to his declination. On the 21st of December, the sun will have the greatest south declination, after which his altitude at the south pole will gradually diminish as his declination diminishes; and on the 21st of March, when the sun's declination is nothing, he will appear to skim along the horizon at the south pole, and likewise at the north pole; the sun has therefore been visible at the south pole for six months.

PROBLEM XXII.

To place the globe in the same situation, WITH RESPECT TO THE POLAR STAR *in the heavens, as our earth is to the inhabitants of the equator, &c. viz. to illustrate the three positions of the sphere,* RIGHT, PARALLEL, *and* OBLIQUE, *so as to show the comparative length of the longest and shortest days.*[*]

I. FOR THE RIGHT SPHERE. — The inhabitants who live upon the equator have a right sphere, and the north polar star appears always in (or very near) the horizon. Place the two poles of the globe in the horizon, then the north pole will correspond with the north polar star, and all the heavenly bodies will *appear* to revolve round the earth from east to west, in circles parallel to the equinoctial, according to their different declinations: one-half of the starry heavens will be constantly above the horizon, and the other half below, so that the stars will be visible for twelve hours, and invisible for the same space of time; and, in the course of a year, an inhabitant upon the equator may see all the stars in the heavens. The ecliptic being drawn on the terrestrial globe, young students are often led to imagine that the sun apparently moves daily round the earth in the same oblique manner. To correct this false idea, we must suppose the ecliptic to be transferred to the heavens, where it properly points out the sun's apparent annual path amongst the fixed stars. The sun's diurnal path is either over the equator, as at the time of the equinoxes, or in lines nearly parallel to the equator; this may be correctly illustrated by fastening one end of a piece of packthread upon the point Aries on the equator, and winding the packthread round the globe towards the right hand, so that one fold may touch another, till you come to the tropic of Cancer; thus you will have a correct view of the sun's apparent diurnal path from the vernal equinox to the summer solstice; for, after a diurnal revolution, the sun does not come to the same point of the parallel whence it departed, but, according as it approaches to or recedes from the tropic, is a little above or below that point. When the sun is in the equinoctial, he will be vertical to all the inhabitants upon the equator, and his apparent diurnal path will be over that line: when the sun has ten degrees of north declination, his apparent diurnal path will be from east to west nearly along that parallel. When the sun has arrived at the tropic of Cancer, his diurnal path in the heavens will be along that line, and he will be vertical to all the inhabitants on the earth in latitude 23° 28′ north. The inhabitants upon the equator will always have twelve hours day and twelve hours night, notwithstanding the variation of the sun's declination from north to south, or from south to north; because the parallel of latitude which the sun apparently describes for any day will always be cut into two equal parts by the horizon. The greatest meridian altitude of the sun will be 90°, and the least 66° 32′. During one half of the year, an inhabitant on the equator will see the sun full north at noon, and during the other half it will be full south.

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[*] In this problem, and in all others where the pole is elevated to the latitude of a given place, the earth is supposed to be fixed, and the sun to move round it from east to west. When the given place is brought to the brass meridian, the wooden horizon is the true rational horizon of that place, but it does not separate the enlightened part of the globe from the dark part, as in the preceding problem.

II. FOR THE PARALLEL SPHERE. — The inhabitants (if any) who live at the north pole have a parallel sphere, and the north polar star in the heavens appears exactly (or very nearly) over their heads. Elevate the north pole ninety degrees above the horizon; then the equator will coincide with the horizon, and all the parallels of latitude will be parallel thereto. In the summer half year, that is, from the vernal to the autumnal equinox, the sun will appear above the horizon, consequently the stars and planets will be invisible during that period. When the sun enters Aries, on the 21st March, he will be seen by the inhabitants of the north pole (if there be any inhabitants) to skim just along the edge of the horizon: and as he increases in declination, he will increase in altitude, forming a kind of spiral course, as before described, by wrapping a thread round the globe. The sun's altitude at any particular hour is always equal to his declination. The greatest altitude the sun can have is 23° 28′, at which time he has arrived at the tropic of Cancer; after which he will gradually decrease in altitude as his declination decreases. When the sun arrives at the sign Libra, he will again appear to skim along the edge of the horizon, after which he will totally disappear, having been above the horizon for six months. Though the inhabitants at the north pole will lose sight of the sun a short time after the autumnal equinox, yet the twilight will continue for nearly two months; for the sun will not be 18° below the horizon till he enters the 20th of Scorpio, as may be seen by the globe.

After the sun has descended 18° below the horizon, all the stars in the northern hemisphere will become visible, and appear to have a diurnal revolution round the heavens from east to west, as the sun appeared to have when he was above the horizon. These stars will not set during the winter half of the year; and the planets, when they are in any of the northern signs, will be visible. The inhabitants under the north polar star have the moon constantly above their horizon during fourteen revolutions of the earth on its axis, and at every full moon which happens, from the 23rd of September to the 21st of March, the moon is in some of the northern signs, and consequently visible at the north pole; for the sun being below the horizon at that time, the moon must be above the horizon, because she is always in that sign which is diametrically opposite to the sun at the time of full moon.

When the sun is at his greatest depression below the horizon, being then in Capricorn, the moon is at her FIRST QUARTER in Aries: FULL in Cancer; and at her THIRD QUARTER in Libra: and as the beginning of Aries is the rising point of the ecliptic, Cancer the highest, and Libra the setting point, the moon rises at her FIRST QUARTER in Aries, is most elevated above the horizon, and FULL in Cancer, and sets at the beginning of Libra in her THIRD QUARTER; having been visible for fourteen revolutions of the earth on its axis, viz. during the moon's passage from Aries to Libra. Thus the north pole is supplied one-half of the winter time with constant moon-light in the sun's absence; and the inhabitants only lose sight of the moon from her THIRD to her FIRST QUARTER, while she gives but little light, and can be of little or no service to them.

III. FOR THE OBLIQUE SPHERE.—Whenever the terrestrial globe is placed in a proper situation with respect to the fixed stars, the pole must be elevated as many degrees above the horizon as are equal to the latitude of the given place, and the north pole of the globe must point to the north polar star in the heavens; for in sailing, or travelling from the equator northward, the north polar star appears to rise higher and higher. On the equator it will appear in the horizon; in ten degrees of north latitude it will be ten degrees above the horizon; in twenty degrees of north latitude it will be twenty degrees above the horizon; and so on, always increasing in altitude as the latitude increases. Every inhabitant of the earth, except those who live upon the equator, or exactly under the north polar star, has an oblique sphere, viz. the equator cuts the horizon obliquely. By elevating and depressing the poles, in several problems, a young student is sometimes led to imagine that the earth's axis moves northward and southward just as the pole is raised or depressed: this is a mistake, the earth's axis has no such motion.* In travelling from the equator northward, our horizon varies; thus, when we are on the equator, the northern point of our horizon is exactly opposite the north polar star; when we have travelled to ten degrees north latitude, the north point of our horizon is ten degrees below the pole, and so on: now, the wooden horizon on the terrestrial globe is immovable, otherwise it ought to be elevated or depressed, and not the pole; but whether we elevate the pole ten degrees above the horizon, or depress the north point of the horizon ten degrees below the pole, the appearance will be exactly the same.

The latitude of London is about 51½ degrees north: if London be brought to the brass meridian, and the north pole be elevated 51½ degrees above the north point of the wooden horizon, then the wooden horizon will be the true horizon of London; and, if the artificial globe be placed exactly north and south by a mariner's compass, or by a meridian line, it will have *exactly* the position which the *real globe* has. Now, if we imagine lines to be drawn through every degree* within the torrid zone, parallel to the equator, they will nearly represent the sun's diurnal path on any given day. By comparing these diurnal paths with each other, they will be found to increase in length from the equator northward, and to decrease in length from the equator southward; consequently, when the sun is north of the equator, the days are increasing in length; and when south of the equator, the days are decreasing. The sun's meridian altitude for any day may be found by counting the number of degrees from the parallel in which the sun is on that day, towards the horizon, upon the brass meridian; thus, when the sun is in that parallel of latitude which is ten degrees north of the equator, his meridian altitude will be 48½ degrees. Though the wooden horizon be the true horizon of the given place, yet it does not separate the enlightened hemisphere of the globe from the dark hemisphere, when the pole is thus elevated. For instance, when the sun is in Aries, and London at the meridian, all the places on the globe above the horizon beyond those meridians which pass through the east and west points thereof, reckoning towards the north, are in darkness, notwithstanding they are above the horizon: and all places below the horizon, between those same meridians and the southern point of the horizon, have day-light, notwithstanding they are below the horizon of London.

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* The earth's axis has a kind of librating motion, called the *nutation*, but this is so very minute that it cannot be represented by elevating or depressing the pole.

PROBLEM XXIII.

The day of the month being given, to find all places of the earth where the sun is vertical on that day; those places where the sun does not set, and those places where he does not rise on the given day.

RULE.—Find the sun's declination (by Problem XX.) for the given day, and turn the globe on its axis, and all the places which pass under the declination will have the sun vertical on that day.

Secondly.—Elevate the north or south pole, according as the sun's declination is north or south, so many degrees above the horizon as are equal to the sun's declination: turn the globe on its axis: then, to those places which do not descend below the horizon, in that frigid zone near the elevated pole, the sun does not set on the given day: and to those places which do not ascend above the horizon, in that frigid zone adjoining to the depressed pole, the sun does not rise on the given day.

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* Such lines are drawn on ADAMS' globes.

OR, BY THE ANALEMMA.

Find the sun's declination by bringing the analemma to the brass meridian and proceed as above.

EXAMPLES.—1. Find all places of the earth where the sun is vertical on the 11th of May, those places in the north frigid zone where the sun does not set, and those places in the south frigid zone where he does not rise.

Answer. The sun is vertical at St. Anthony, one of the Cape Verd Islands, the Virgin Islands, south of St. Domingo, Jamaica, Golconda, &c. All the places within eighteen degrees of the north pole will have constant day; and those (if any) within eighteen degrees of the south pole will have constant night.

2. Whether does the sun shine over the north or south pole on the 27th of October, to what places will he be vertical at noon, what inhabitants of the earth will have the sun below their horizon during several revolutions, and to what part of the globe will the sun never set on that day?

3. Find all the places of the earth where the inhabitants have no shadow when the sun is on their meridian on the first of June.

4. What inhabitants of the earth have their shadows directed to every point of the compass during a revolution of the earth on its axis on the 15th of July?

5. How far does the sun shine over the south pole on the 14th of November, what places in the north frigid zone are in perpetual darkness, and to what places is the sun vertical?

6. Find all places of the earth where the moon was vertical on the 26th of June, 1845.* See p. 283.†

What places will have the sun vertical, and to what places will he not set, and to what places will he not rise on the following days?

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* To perform this example, find the moon's declination on the given day in the Nautical Almanac, or White's Ephemeris, and mark it on the brass meridian; all places passing under that degree of declination will have the moon vertical, or nearly so, on the given day.

† The moon's declination at midnight on the 26th of June, 1845, by the Nautical Almanac, is 7°8′ 59″·8 N.

7. January 1.
8. February 7.
9. March 11.
10. April 22.
11. May 19.
12. June 21.
13. August 11.
14. September 23.
15. October 11.

PROBLEM XXIV.

A place being given in the torrid zone, to find those two days of the year on which the sun will be vertical at that place.

RULE.—Bring the given place to the brass meridian, and mark its latitude; turn the globe on its axis, and observe what two points of the ecliptic pass under that latitude: seek those points of the ecliptic in the circle of signs on the horizon, and against them, in the circle of months, stand the days required.

OR, BY THE ANALEMMA.

Find the latitude of the given place; bring the analemma to the brass meridian, upon which, under the latitude, will be found the two days required.

EXAMPLES.—1. On what two days of the year will the sun be vertical at Madras?

Answer. On the 25th of April and on the 18th of August.

On what two days of the year is the sun vertical at the following places?

2. Owhyhee
3. Friendly Isles
4. Straits of Macassar
5. Penang
6. Trincomalé
7. St. Helena
8. Rio Janeiro
9. Quito
10. Barbadoes
11. Porto Bello
12. Sierra Leone
13. Vera Cruz
14. Manilla
15. Tinian Isle
16. Pelew Islands.

PROBLEM XXV.

The day of the month being given, to find what other day of the year is of the same length.

RULE.—Find the sun's place in the ecliptic for the given day (by Problem XX.); bring it to the brass meridian, and observe the degree above it; turn the globe on its axis till some other point of the ecliptic falls under the same degree of the meridian: find this point of the ecliptic on the horizon, and against it you will find the day of the month required.

This Problem may be performed by the celestial globe in the same manner.

OR, BY THE ANALEMMA.

Look for the given day of the month on the analemma, and adjoining to it you will find the required day of the month.

OR, WITHOUT A GLOBE.

Any two days of the year which are of the same length will be an equal number of days from the longest or shortest day. Hence, whatever number of days the given day is before the longest or shortest day, just so many days will the required day be after the longest or shortest day, *et contra.*

EXAMPLES.—1. What day of the year is of the same length as the 25th of April?

Answer. The 18th of August.

2. What day of the year is of the same length as the 25th of May?

3. If the sun rise at four o'clock in the morning at London on the 17th of July, on what other day of the year will it rise at the same hour?

4. If the sun set at seven o'clock in the evening at London on the 24th of August, on what other day of the year will it set at the same hour?

5. If the sun's meridian altitude be 90° at Trincomalé, in the Island of Ceylon, on the 12th of April, on what other day of the year will the meridian altitude be the same?

6. If the sun's meridian altitude at London on the 25th of April be 51° 35′, on what other day of the year will the meridian altitude be the same?

7. If the sun be vertical at any place on the 15th of April, how many days will elapse before he is vertical a second time at that place?

8. If the sun be vertical at any place on the 20th of August, how many days will elapse before he is vertical a second time at that place?

PROBLEM XXVI.

The month, day, and hour of the day being given, to find where the sun is vertical at that instant.

RULE.—Find the sun's declination (by Problem XX.), bring the given place to the brass meridian, and set the index of the hour-circle to the given time, turn the globe on its axis until the index points to noon; the place immediately under the sun's declination is that to which the sun is vertical at the proposed time.

EXAMPLES.—1. When it is forty minutes past six o'clock in the morning at London on the 25th of April, where is the sun vertical?

Answer. Madras.

2. When it is four o'clock in the afternoon at London on the 18th of August, where is the sun vertical?

Answer. Barbadoes.

3. When it is three o'clock in the afternoon at London on the 4th of January, where is the sun vertical?

4. When it is three o'clock in the morning at London on the 11th of April, where is the sun vertical?

5. When it is thirty-seven minutes past one o'clock in the afternoon at the Cape of Good Hope on the 5th of February, where is the sun vertical?

6. When it is eleven minutes past one o'clock in the afternoon at London on the 29th of April, where is the sun vertical?

7. When it is twenty minutes past five o'clock in the afternoon at Philadelphia on the 18th of May, where is the sun vertical?

8. When it is nine o'clock in the morning at Calcutta on the 11th of April, where is the sun vertical?

9. Where is the sun vertical, when it is 6 A.M. at Cairo on February 22?

10. On October 24, when it is 10 minutes past 7 A.M. at Otaheite, where is the sun vertical?

11. On April 25, where is the sun vertical, when it is 4 P.M. at London?

12. Where is the sun vertical on May 17, when it is 5 A.M. at Siam?

13. Where is the sun vertical on May 20, when it is 7 P. M. at Amsterdam?

14. The inhabitants of what city will have no shadow on June 10, when it is 6 minutes past 6 A. M. at London?

PROBLEM XXVII.

The month, day, and hour of the day at any place being given, to find all those places of the earth where the sun is rising, those places where the sun is setting, those places that have noon, that particular place where the sun is vertical, those places that have morning twilight, those places that have evening twilight, and those places that have midnight.

RULE.—Find the sun's declination; elevate the pole equal to the sun's declination; bring the given place to the brass meridian, and set the index to the given hour; turn the globe on its axis until the index points to noon; then all places along the western edge of the horizon have the sun rising; those places along the eastern edge have the sun setting; those under the brass meridian above the horizon have noon; that particular place which stands under the sun's declination on the brass meridian has the sun vertical; all places below the western edge of the horizon, within eighteen degrees, have morning twilight; those places which are below the eastern edge of the horizon, within eighteen degrees, have evening twilight; all places under the brass meridian below the horizon have midnight; all places above the horizon have day, and those below it have night or twilight.

EXAMPLES.—1. When it is fifty-two minutes past four o'clock in the morning at London on the 5th of March, find all places of the earth where the sun is rising, setting, &c. &c.

Answer. The sun is rising at the western part of the White Sea, Petersburg, the Morea in Turkey, &c.

Setting at the eastern coast of Kamtschatka, Jesus Island, Palmerston Island, &c., between the Friendly and Society Islands, &c.

Noon at the Lake Baikal, in Irkoutsk, Cochin China, Cambodia, Sunda Islands, &c.

Vertical at Batavia.

Morning twilight at Sweden, part of Germany, the southern part of Italy, Sicily, the western coast of Africa along the Ethiopian Ocean, &c.

Evening twilight at the north-west extremity of North America, the Sandwich Islands, Society Islands, &c.

Midnight at Labrador, New York, western part of St. Domingo, Chili, and the western coast of South America.

Day at the eastern part of Russia in Europe, Turkey, Egypt, the Cape of Good Hope, and all the eastern part of Africa, almost the whole of Asia, &c.

Night at the whole of North and South America, the western part of Africa, the British Isles, France, Spain, Portugal, &c.

2. When it is four o'clock in the afternoon at London on the 25th of April, where is the sun rising, setting, &c. &c.?

Answer. The sun will be *rising* at Owhyhee, &c.; *setting* at the Cape of Good Hope, &c.; it will be *noon* at Buenos Ayres, &c.; the sun will be *vertical* at Barbadoes; and, following the directions in the Problem, all the other places are readily found.

3. When it is ten o'clock in the morning at London on the longest day, to what countries is the sun rising, setting, &c. &c.?

4. When it is ten o'clock in the afternoon at Botany Bay on the 15th of October, where is the sun rising, setting, &c. &c.?

5. When it is seven o'clock in the morning at Washington on the 17th of February, where is the sun rising, setting, &c. &c.?

6. When it is midnight at the Cape of Good Hope on the 27th of July, where is the sun rising, setting, &c. &c.?

To what places will the sun be rising, setting, &c. &c., at the undermentioned places on the given days:—

7. January 1, when it is 3 A.M. at London?
8. April 17, when it is 4 P.M. at Lima?
9. May 17, when it is 8 P.M. at Petersburg?
10. August 11, when it is 4 P.M. at Botany Bay?
11. October 11, when it is 9 P.M. at Calcutta?
12. December 25, when it is 2 P.M. at Liverpool?
13. January 17, when it is 5 P.M. at Paris?
14. February 5, when it is 9 P.M. at Vienna?

PROBLEM XXVIII.

To find the time of the sun's rising and setting, and length of the day and night, at any place not in the frigid zones.

RULE.—Elevate the pole equal to the sun's declination; bring the given place to the brass meridian, and set the index of the hour-circle to 12; turn the globe till the given place comes to the eastern semicircle of the horizon, and the index* will show the time of the sun's rising; turn the globe till the given place comes to the western edge of the horizon and the index will show the time of his setting, or either of these taken from 12 will give the other, because the sun is an equal time above the horizon, both before and after 12. Double the time of the sun's setting gives the length of the day, and double the time of rising gives the length of the night.

By the same rule, the length of the *longest* day, at all places not in the frigid zones, may be readily found; for the longest day at all places in north latitude is on the 21st of June, or when the sun enters Cancer; and the longest day at all places in south latitude is on the 21st of December, or when the sun enters the sign Capricorn.

OR,

Elevate the pole equal to the latitude; find the sun's place in the ecliptic; bring it to the brass meridian, and set the index to 12; turn the globe till the sun's place come to the eastern semicircle of the horizon, and the index will show the time of the sun's rising; turn the globe, till the sun's place comes to the western edge of the horizon, and the index will show the time of his setting; then, as before, double the time of setting gives the length of the day, and double the time of rising gives the length of the night.

OR, BY THE ANALEMMA.

Elevate the pole, according to the latitude; bring the middle of the analemma to the brass meridian, and set the index of the hour-circle to 12; turn the globe till the day of the month on the analemma comes to the eastern or western semicircle of the horizon, and the index will show the time of the sun's rising, setting, &c. as above.

EXAMPLES.—1. What time does the sun rise and set at London on the 1st of June, and what is the length of the day and night?

Answer. The sun sets at 8 min. past 6, and rises at 54 min. past 3; the length of the day is 16 hours 12 minutes, and the length of the night 7 hours 48 minutes.

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* If the hour circle have a double row of figures, it will show the time of the sun's rising and setting both at once.

At what time does the sun rise and set at the following places, on the respective days mentioned, and what is the length of the day and night?

2. London, 17th of May
3. Gibraltar, 22nd of July
4. Edinburgh, 29th January
5. BotanyBay, 20th February
6. Pekin, 20th of April
7. Cape of Good Hope, 7 Dec.
8. Cape Horn, 29th January
9. Washington, 15th Decem.
10. Petersburg, 24th October
11. Constantinople, 18th Aug.

12. Find the time the sun rises and sets at any place on the surface of the globe on the 21st of March, and likewise on the 23rd of September.

Required the length of the longest day and shortest night at the following places:

13. London
14. Petersburg
15. Aberdeen
16. Dublin
17. Glasgow
18. Paris
19. Vienna
20. Berlin
21. Buenos Ayres
22. Botany Bay
23. Pekin
24. Cape Horn
25. Washington
26. Cape of Good Hope
27. Copenhagen.

Required the length of the shortest day and longest night at the following places:

28. London
29. Archangel
30. Otaheite
31. Quebec
32. Lima
33. Mexico
34. St. Helena
35. Alexandria
36. Paris
37. Owhyhee
38. Lisbon
39. Falkland islands.

40. How much longer is the 21st of June at Petersburg than at Alexandria?

41. How much longer is the 21st of December at Alexandria than at Petersburg?

42. At what time does the sun rise and set at Spitzbergen on the 5th of April?

PROBLEM XXIX.

The length of the day at any place being given, to find the sun's declination and the day of the month.

RULE. Bring the given place to the brass meridian and set the index to 12; turn the globe till the index points to the hour of sunset, which is half the length of the day; keep the globe from revolving on its axis, and elevate or depress the poles till the given place exactly coincides with the eastern semicircle of the horizon; the elevation of the pole will be the sun's declination: turn the globe on its axis, and observe what two points of the ecliptic pass under the declination; seek those points in the circle of signs on the horizon, and against them will be found the days of the months required.

OR,

Bring any meridian to the brass meridian, elevate the pole to the latitude of the place, and set the index of the hour-circle to 12; turn the globe eastward till the index has passed over as many hours as are equal to half the length of the day, and mark where the above meridian is cut by the eastern semicircle of the horizon; bring this mark to the brass meridian, and the degree above it is the sun's declination; with which proceed as above.*

OR, BY THE ANALEMMA.

Bring the middle of the analemma to the brass meridian, elevate the pole to the latitude of the place, and set the index of the hour-circle to 12; turn the globe eastward till the index has passed over as many hours as are equal to half the length of the day; the two days, on the analemma, which coincide with that point of the meridian passing through the middle of the analemma which is cut by the eastern semicircle of the horizon, will be the days required; and, by bringing the analemma to the brass meridian, the sun's declination will stand above these days.

EXAMPLES.—1. What two days in the year are each sixteen hours long at London, and what is the sun's declination?

Answer. The 24th of May and the 17th of July. The sun's declination is about 21° north.

2. What two days of the year are each fourteen hours long at London?

3. On what two days of the year does the sun set at half-past seven o'clock at Edinburgh?

4. On what two days of the year does the sun rise at four o'clock at Petersburg?

5. What two nights of the year are each ten hours long at Copenhagen?

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* If Newton's globes be used, the graduated meridian is that which passes through Cancer; and which will be found most convenient for working this problem.

6. What day of the year at London is sixteen hours and a half long?

7. What is the sun's declination when the day is fourteen hours long at London?

8. What is the sun's declination when the day at Petersburg is seven hours long?

9. On what two days does the sun set at Edinburgh at 8?

10. On what two days does the sun rise at 4 at Liverpool?

11. On what two days does the sun set at 7 at Dover?

12. Observed the sun set at Madrid at 7 in the spring, what was the day of the month?

13. Observed the sun rise at London at ½ past 4, what was his declination, and the day of the month?

14. On what two days does the sun set at 7 at Vienna?

PROBLEM XXX.

To find the length of the longest day at any place in the north frigid zone.

RULE. Subtract the latitude of the place from 90, and find the degree on the brass meridian to the north of the equator which is like the remainder. Turn the globe, and observe the two points of the ecliptic passing under this degree, and find the days coinciding with them on the horizon. The day before the 21st of June will show the beginning, and the other the end, of the longest day, or continued daylight: the space between these two days will be the length of the longest day.

OR, BY THE ANALEMMA.

Find the degree on the brass meridian as directed above; then bring the analemma to the brass meridian, and the two days which stand under the above mark will point out the beginning and end of the longest day.

EXAMPLES. 1. What is the length of the longest day at the North Cape, in the island of Maggeroe, in latitude 71° 30′ north?

Answer. The place is 18½° from the pole; the longest day begins on the 14th of May, and ends on the 30th of July; the day is therefore seventy-seven days long, that is, the sun does not set during seventy-seven revolutions of the earth on its axis.

2. What is the length of the longest day in the north of Spitzbergen, and on what days does it begin and end?

3. What is the length of the longest day at the northern extremity of Nova Zembla?

4. What is the length of the longest day at the North Pole, and on what days does it begin and end?

5. What is the length of the longest day at Melville Island?

How long does the sun shine without setting in places in the following latitudes?

6. 73° N.
7. 75° N.
8. 77° N.
9. 79° N.
10. 81° N.
11. 83° N.
12. 85° N.
13. 87° N.

PROBLEM XXXI.

To find the length of the longest night at any place in the north frigid zone.

RULE. The method of working this problem is exactly like the last, only observing to read south for north, and Dec. 21. for June 21.

EXAMPLES. 1. What is the length of the longest night at the North Cape, in the island of Maggeroe, in latitude 71° 30′ north?

Answer. The place is 18½° from the pole: the longest night begins on the 16th of November, and ends on the 27th of January: the night is therefore seventy-three days long, that is, the sun does not rise during seventy-three revolutions of the earth on its axis.

2. What is the length of the longest night at the north of Spitzbergen?

3. The Dutch wintered in Nova Zembla, latitude 76° north, in the year 1596; on what day of the month did they lose sight of the sun; on what day of the month did he appear again; and how many days were they deprived of his appearance, setting aside the effect of refraction?

4. For how many days are the inhabitants of the northernmost extremity of Russia deprived of a sight of the sun?

PROBLEM XXXII.

To find the number of days which the sun rises and sets at any place in the north frigid zone.*

RULE. Subtract the latitude of the place from 90°, and observe on the brass meridian those two points, one on the north and the other on the south of the equator, which are like the remainder; observe what two points of the ecliptic nearest to Aries pass under the above marks; these points will show (upon the horizon) the end of the longest night and the beginning of the longest day; during the time between these days the sun will rise and set every twenty-four hours; next observe what two points of the ecliptic, nearest to Libra, pass under the marks on the brass meridian; find these points, as before, in the circle of signs, and against them you will find the day on which the longest day ends at the given place, and the day on which the longest night begins; during the time between these days, the sun will rise and set every twenty-four hours.

OR,

Find the length of the longest day at the given place (by Prob. XXX.) and the length of the longest night (by Prob. XXXI.); add these together, and subtract the sum from 365 days, the length of the year; the remainder will show the number of days which the sun rises and sets at that place.

OR, BY THE ANALEMMA.

Find how many degrees the given place is from the north pole, and mark those degrees upon the brass meridian on both sides of the equator; observe what four days on the analemma stand under the marks on the brass meridian; the time between those two days on the left-hand part of the analemma (reckoning towards the north pole) will be the number of days on which the sun rises and sets, between the end of the longest night and the beginning of the longest day; and the time between the two days on the right-hand part of the analemma (reckoning towards the south pole) will be the number of days on which the sun rises and sets, between the end of the longest day and the beginning of the longest night.

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* The same might be found for a place in the south frigid zone, were that zone inhabited.

EXAMPLES.—1. How many days in the year does the sun rise and set at the North Cape, in the island of Maggeroe, in latitude 71° 30′ north?

Answer. The place is 18½° from the pole; the two points in the ecliptic, *nearest to Aries*, which pass under 18½° on the brass meridian, are 8° in ♒, answering to the 27th of January, and 24° in ♉, answering to the 14th of May. Hence the sun rises and sets for 107 days, viz. from the end of the longest night, which happens on the 27th of January to the beginning of the longest day, which happens on the 14th of May. *Secondly*, the two points in the ecliptic *nearest to Libra*, which pass under 18½° on the brass meridian, are 8° in ♌, answering to the 30th of July, and 24° in ♏, answering to the 15th of November. Hence the sun rises and sets for 108 days, viz. from the end of the longest day, which happens on the 30th of July, to the beginning of the longest night, which happens on the 15th of November; so that the whole time of the sun's rising and setting is 215 days.

OR, THUS:

The length of the longest day, by Example 1st, Prob. XXX. is 77 days; the length of the longest night, by Example 1st, Prob. XXXI. is 73 days; the sum of these is 150, which, deducted from 365, leaves 215 days as above.

2. How many days in the year does the sun rise and set at the north of Spitzbergen?

3. How many days does the sun rise and set at Greenland, in latitude 75° north?

4. How many days does the sun rise and set at the northern extremity of Russia in Asia?

How many days does the sun rise and set in the following latitudes?

5. 73° N. 7. 79° N. 9. 84° N.
6. 77° N. 8. 82° N. 10. 86° N.

PROBLEM XXXIII.

To find in what degree of north latitude, on any day between the 21st of March and the 21st of June, or in what degree of south latitude, on any day between the 23rd of September and the 21st of December, the sun begins to shine constantly without setting; and also in what latitude in the opposite hemisphere he begins to be totally absent.

RULE. Subtract the sun's declination for the given day from 90, the remainder is the answer.

EXAMPLES. 1. In what latitude north, and at what places, does the sun begin to shine without setting during several revolutions of the earth on its axis, on the 14th of May?

Answer. The sun's declination is 18½° north; therefore all places in latitude 71½° north will be the places sought, viz. the North Cape in Lapland, the southern part of Nova Zembla, Icy Cape, &c.

2. In what latitude south does the sun begin to shine without setting on the 18th of October, and in what latitude north does he begin to be totally absent?

Answer. The sun's declination is 10° south; therefore he begins to shine constantly in latitude 80° south, where there are no inhabitants known, and to be totally absent in latitude 80° north, viz. at Spitzbergen.

3. In what latitude does the sun begin to shine without setting on the 20th of April?

4. In what latitude north does the sun begin to shine without setting on the 1st of June, and in what degree of south latitude does he begin to be totally absent?

In what latitude does the sun begin to shine without setting on the following days?

5. March 30. 7. May 1. 9. May 30.
6. April 10. 8. May 15. 10. June 7.

PROBLEM XXXIV.

Any number of days, not exceeding 182, *being given, to find the parallel of north latitude in which the sun does not set for that time.*

RULE. Count half the number of days from the 21st of June on the horizon, eastward or westward, and opposite to the last day you will find the sun's place in the circle of signs: look for the sign and degree on the ecliptic, which bring to the brass meridian, and observe the sun's declination: subtract this declination from 90, and you will have the latitude sought.

EXAMPLES. 1. In what degree of north latitude, and at what places, does the sun continue above the horizon for seventy-seven days?

Answer. Half the number of days is 38½, and if reckoned backward, or towards the east, from the 21st of June, will answer to the 14th of May; and if counted forward, or towards the west, will answer to the 30th of July; on either of which days the sun's declination is 18½ degrees north, consequently the places sought are 18½ degrees from the north pole, or in latitude 71½ degrees north; answering to the North Cape in Lapland, the south part of Nova Zembla, Icy Cape, &c.

2. In what degree of north latitude is the longest day 134 days, or 3216 hours in length?

3. In what degree of north latitude does the sun continue above the horizon for 2160 hours?

4. In what degree of north latitude does the sun continue above the horizon for 1152 hours?

In what degree of north latitude does the sun shine without setting for the following number of days?

5. 24 days.
6. 36 „
7. 40 „
8. 56 days.
9. 64 „
10. 84 „
11. 96 days.
12. 108 „
13. 120 „

PROBLEM XXXV.

To find the beginning, end, and duration of twilight at any given place on any given day.

RULE. Find the sun's declination for the given day, and elevate the pole equal to it; screw the quadrant of altitude on the brass meridian, over the degree of the sun's declination; bring the given place to the brass meridian, and set the index of the hour-circle to 12; turn the globe eastward till the given place comes to the horizon, and the index will show the time of the sun's setting, or the beginning of evening twilight; continue the motion of the globe eastward, till the given place coincides with 18° on the quadrant of altitude below the horizon, and the index will show when evening twilight ends. The time when evening twilight ends, subtracted from 12, will show the beginning of morning twilight, which is of the same length as the evening.

OR, THUS:

Elevate the pole equal to the latitude of the given place; find the sun's place in the ecliptic; bring it to the brass meridian; set the index of the hour-circle to 12, and screw the quadrant of altitude upon the brass meridian over the given latitude: turn the globe westward on its axis till the sun's place comes to the western edge of the horizon, and the index will show the time of the sun's setting, or the beginning of evening twilight; continue the motion of the globe westward till the sun's place coincides with 18° on the quadrant of altitude below the horizon: the index will show the end of evening twilight. Subtract the beginning from the end for the duration of evening twilight.

OR, BY THE ANALEMMA.

Work exactly the same as in the above rule, only use the day of the month on the analemma instead of the sun's place in the ecliptic.

EXAMPLES. 1. Required the beginning, end, and duration of morning and evening twilight at London on the 19th of April.

Answer. The sun sets at two minutes past seven, and evening twilight ends at nineteen minutes past nine; consequently morning twilight begins at (12h. — 9h. 19m. =) 2h. 41m. and ends at (12h. — 7h. 2m. =) 4h. 58m.; the duration of twilight is 2h. and 17 minutes.

2. What is the duration of twilight at London on the 23rd of September; what time does dark night begin, and at what time does day break in the morning?

Answer. The sun sets at six o'clock, and the duration of twilight is two hours; consequently the evening twilight ends at eight o'clock, and the morning twilight begins at four.

3. Required the beginning, end, and duration of morning and evening twilight at London on the 25th of August.

4. Required the beginning, end, and duration of morning and evening twilight at Edinburgh on the 20th of February.

5. Required the beginning, end, and duration of morning and evening twilight at Cape Horn on the 20th of February.

6. Required the beginning, end, and duration of morning and evening twilight at Madras on the 15th of June.

Required the beginning, end, and duration of twilight at the following places on the respective days:

7. Quito, May 1.
8. Lima, December 1.
9. New Orleans, March 9.
10. Charlestown, June 10.
11. Quebec, May 1.
12. Edinburgh, April 7.
13. Paris, February 6.
14. Oporto, June 7.

PROBLEM XXXVI.

To find the beginning, end, and duration of constant day or twilight at any place.

RULE. Add 18 to the latitude of the place, and subtract the sum from 90. Find the degree on the brass meridian which is like the remainder, and on the same side of the equator as the given place, and observe what two points of the ecliptic pass under that degree*; that point wherein the sun's declination is increasing will show on the horizon the beginning of constant twilight; and that point wherein the sun's declination is decreasing, will show the end of constant twilight.

EXAMPLES. 1. When do we begin to have constant day or twilight at London, and how long does it continue?

Answer. The latitude of London is 51½ degrees north, to which add 18 degrees, the sum is 69½; subtract 69½ from 90, the remainder is 20½; the two points of the ecliptic which pass under 20½ N. declination are two degrees in ♊, answering to the 22nd of May, and 29 degrees in ♋, answering to the 21st of July; so that, from the 22nd of May to the 21st of July the sun never descends 18 degrees below the horizon of London.

2. When do the inhabitants of the Shetland Islands cease to have constant day or twilight?

3. Can twilight ever continue from sun-set to sun-rise at Madrid?

4. When does constant day or twilight begin at Spitzbergen?

5. What is the duration of constant day or twilight at the North Cape in Lapland, and on what day, after their long winter's night, do the sun's rays first enter the atmosphere?

When does constant day or twilight begin and end at the following places?

6. Copenhagen
7. Amsterdam
8. Cape Horn
9. Quebec.

What is the duration of constant day or twilight at the following places?

10. Inverness
11. Glasgow
12. Newcastle
13. York
14. Liverpool
15. Exeter.

PROBLEM XXXVII.

To find the duration of twilight at the north pole.

RULE. Elevate the north pole so that the equator may coincide with the horizon; observe what point of the ecliptic nearest to Libra passes under 18° below the horizon, reckoned on the brass meridian, and find the day of the month correspondent thereto; the time elapsed from the 23rd of September to this time will be the duration of evening twilight. Secondly, observe what point of the ecliptic, nearest to Aries, passes under 18° below the horizon, reckoned on the brass meridian, and find the day of the month correspondent thereto; the time elapsed from that day to the 21st of March will be the duration of morning twilight.

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* If, after 18 degrees be added to the latitude, the distance from the pole will not reach the ecliptic, there will be no constant twilight at the given place, *viz.* to the given latitude add 18 degrees, and subtract the sum from 90; if the remainder exceed 23½ degrees, there can be no constant twilight at the given place.

EXAMPLE. What is the duration of twilight at the north pole, and what is the duration of dark night there?

Answer. The point of the ecliptic nearest to Libra which passes under 18 degrees below the horizon is 22 degrees in ♏, answering to the 13th of November; hence the evening twilight continues from the 23rd of September (the end of the longest day) to the 13th of November (the beginning of dark night), being 51 days. The point of the ecliptic nearest to Aries which passes under 18 degrees below the horizon is 9 degrees in ♒, answering to the 29th of January; hence the morning twilight continues from the 29th of January to the 21st of March (the beginning of the longest day), being 51 days. From the 23rd of September to the 21st of March are 179 days, from which deduct 102 (=51 × 2), the remainder is 77 days, the duration of total darkness at the north pole; but, even during this short period, the moon and the Aurora Borealis shine with uncommon splendour.

PROBLEM XXXVII.

To find in what climate any given place on the globe is situated.

RULE. 1. If the place be not in the frigid zone, find the length of the longest day at that place (by Problem XXVIII.) and subtract twelve hours therefrom; the number of half hours in the remainder will show the climate.

2. If the place be in the frigid zone*, find the length of

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* The climates between the polar circles and the poles were unknown to the ancient geographers; they reckoned only seven climates north of the equator. The middle of the first northern climate they made to pass through *Meroe*, a city of Ethiopia, built by Cambyses on an island in the Nile nearly under the tropic of Cancer; the second through *Syene*, a city of Thebais in Upper Egypt, near the cataracts of the Nile; the third through *Alexandria;* the fourth through *Rhodes;* the fifth through *Rome* or the *Hellespont;* the sixth through the mouth of the *Borysthenes* or *Dnieper;* and the seventh through the *Riphhæan mountains*, supposed to be situated near the source of the Tanais or Don river. The southern parts of the earth being in a great measure unknown, the climates re-

the longest day at that place (by Problem XXX.), and if that be less than thirty days, the place is in the twenty-fifth climate, or the *first* within the polar circle. If more than thirty and less than sixty, it is in the twenty-sixth climate, or the *second* within the polar circle; if more than sixty, and less than ninety, it is in the twenty-seventh climate, or the *third* within the polar circle, &c.

EXAMPLES. 1. In what climate is London, and what other remarkable places are situated in the same climate?

Answer. The longest day in London is 16½ hours; if we deduct 12 therefrom, the remainder will be 4½ hours, or nine half hours; hence London is in the ninth climate north of the equator; and as all places in or near the same latitude are in the same climate, we shall find Amsterdam, Dresden, Warsaw, Irkoutsk, the southern part of the peninsula of Kamtschatka, Nootka Sound, the south of Hudson's Bay, the north of Newfoundland, &c. to be in the same climate as London. The learner is requested to turn to the note to Definition 69th, page 17.

2. In what climate is the North Cape, in the island of Maggeroe, latitude 71° 30′ north?

Answer. The length of the longest day is 77 days: these days divided by 30 give two months for the quotient, and a remainder of 17 days; hence the place is in the *third* climate within the polar circle, or the 27th climate, reckoning from the equator. The southern part of Nova Zembla, the northern part of Siberia, James' Island, Baffin's Bay, the northern part of Greenland, &c. are in the same climate.

3. In what climate is Edinburgh, and what other places are situated in the same climate?

4. In what climate is the north of Spitzbergen?

5. In what climate is Cape Horn?

6. In what climate is Botany Bay, and what other places are situated in the same climate?

PROBLEM XXXIX.

To find the breadths of the several climates between the equator and the polar circles.

RULE. For the northern climates. Elevate the north pole 23½° above the northern point of the horizon; bring the sign

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ceived their names from the northern ones, and not from particular towns or places. Thus the climate, which was supposed to be at the same distance from the equator southward as Meroe was northward, was called *Antidiameroes*, or the opposite climate to Meroe; *Antidiasyenes* was the opposite climate to Syenes, &c.

Cancer to the meridian, and set the index to 12: turn the globe eastward on its axis till the index has passed over a quarter of an hour; observe that particular point of the meridian passing through Libra, which is cut by the horizon, and at the point of intersection make a mark with a pencil; continue the motion of the globe eastward till the index has passed over another quarter of an hour, and make a second mark; proceed thus till the meridian passing through Libra* will no longer cut the horizon†; the several marks brought to the brass meridian will point out the latitude where each climate ends.‡

EXAMPLES. 1. What is the breadth of the ninth north climate, and what places are situated within it?

Answer. The breadth of the 9th climate is 2° 57′; it begins in latitude 49° 2′ north, and ends in latitude 51° 59′ north, and all places situated within this space are in the same climate. The places will be nearly the same as those enumerated in the first example to the preceding problem.

2. What is the breadth of the second climate, and in what latitude does it begin and end?

3. Required the beginning, end, and breadth of the fifth climate.

4. What is the breadth of the seventh climate north of the equator, in what latitude does it begin and end, and what places are situated within it?

5. What is the breadth of the climate in which Petersburg is situated?

6. What is the breadth of the climate in which Mount Hecla is situated?

In what climate are the following places situated?

7. Lima
8. Mexico
9. Madrid
10. Oporto
11. York
12. Christiana
13. Melville I.

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* On Adams' and Cary's globes the meridian passing through Libra is divided into degrees, in the same manner as the brass meridian is divided; the horizon will, therefore, cut this meridian in the several degrees answering to the end of each climate, without the trouble of bringing it to the brass meridian, or marking the globe.

† On Newton's globes the meridian passing through Cancer is thus divided.

‡ See a Table of the Climates, with the method of constructing it, at pages 16. and 17.

PROBLEM XL.

*To find that part of the equation of time which depends on the obliquity of the ecliptic.**

RULE. Find the sun's place in the ecliptic, and bring it to the brass meridian; count the number of degrees from Aries to the brass meridian, on the equator and on the

SUN *faster than the* CLOCK *in*

Deg.	♈ ♎		♉ ♏		♊ ♐		1 Qu. 3 Qu.
	M.	S.	M.	S.	M.	S.	
0	0	0	8	24	8	46	30
1	0	20	8	35	8	36	29
2	0	40	8	45	8	25	28
3	1	0	8	54	8	14	27
4	1	19	9	3	8	1	26
5	1	39	9	11	7	49	25
6	1	59	9	18	7	35	24
7	2	18	9	24	7	21	23
8	2	37	9	31	7	6	22
9	2	56	9	36	6	51	21
10	3	16	9	41	6	35	20
11	3	34	9	45	6	19	19
12	3	53	9	49	6	2	18
13	4	11	9	51	5	45	17
14	4	29	9	53	5	27	16
15	4	47	9	54	5	9	15
16	5	4	9	55	4	50	14
17	5	21	9	55	4	31	13
18	5	38	9	54	4	12	12
19	5	54	9	52	3	52	11
20	6	10	9	50	3	32	10
21	6	26	9	47	3	12	9
22	6	41	9	43	2	51	8
23	6	35	9	38	2	30	7
24	7	9	9	33	2	9	6
25	7	23	9	27	1	48	5
26	7	36	9	20	1	27	4
27	7	49	9	13	1	5	3
28	8	1	9	5	0	43	2
29	8	13	8	56	0	22	1
30	8	24	8	46	0	0	0
2 Qu. 4 Qu.	♍ ♓		♌ ♒		♋ ♑		Deg.

SUN *slower than the* CLOCK *in*

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* The equation of time, or difference between the time shown by a well-regulated clock, and a true sun-dial, depends upon two causes, viz. the obliquity of the ecliptic, and the unequal motion of the earth in its orbit. The former of these causes may be explained by the above Problem. If two suns were to set off at the same time from the point Aries, and move over equal spaces in equal time, the one on the ecliptic, the other on the equator, it is evident they would never come to the meridian together, except at the time of the equinoxes, and on the longest and shortest days. The annexed table shows how much the sun is faster or slower than the clock ought to be, *so far as the variation depends on the obliquity of the ecliptic only.* The signs of the first and third quadrants of the ecliptic are at the top of the table, and the degrees in these signs on the left hand; in any of these signs the sun is faster than the clock. The signs of the second and third quadrants are at the bottom of the table, and the degrees in these signs at the right hand; in any of these signs the sun is slower than the clock.

Thus, when the sun is in 20° of ♉ or ♏, it is 9 minutes 50 seconds faster than the clock, and when the sun is in 18° of ♋ or ♑, it is 6 minutes 2 seconds slower than the clock.

ecliptic; the difference, reckoning four minutes of time to a degree, is the equation of time. If the number of degrees on the ecliptic exceed those on the equator, the sun is faster than the clock; but if the number of degrees on the equator exceed those on the ecliptic, the sun is slower than the clock.

EXAMPLES. 1. What is the equation of time on the 17th of July?

Answer. The degrees on the equator exceed the degrees on the ecliptic by two: hence the sun is eight minutes slower than the clock.*

2. On what four days of the year is the equation of time nothing?

3. What is the equation of time dependant on the obliquity of the ecliptic on the 27th of October?

4. When the sun is in 18° of Aries, what is the equation of time?

PROBLEM XLI.

To find the sun's meridian altitude at any time of the year at any given place.

RULE. Find the sun's declination, and elevate the pole to that declination; bring the given place to the brass meridian, and count the number of degrees on the brass meridian (the nearest) to the horizon; these degrees will show the sun's meridian altitude.†

OR,

Elevate the pole so many degrees above the horizon as are equal to the latitude of the place; find the sun's place in the ecliptic, and bring it to the brass meridian; count the number of degrees contained in the brass meridian between the sun's place and the horizon, and they will show the altitude.‡

To find the sun's *altitude* at any hour, see Problem XLIV.

OR, BY THE ANALEMMA.

Elevate the pole so many degrees above the horizon as are equal to the latitude of the place; find the day of the month on the analemma, and bring it to that part of the brass meridian which is numbered from the equator towards the poles; count the number of degrees contained on the brass meridian between the given day of the month and the horizon, and they will show the altitude.*

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* The learner will observe, that the equation of time here determined is not the true equation, as noted on the 7th circle on the horizon of Bardin's globes; the equation of time there given cannot be determined by the globe. See the Table at the end of Problem LXIV.

† See Problem XXI.

‡ See Problem XXII.

EXAMPLES. 1. What is the sun's meridian altitude at London on the 21st of June?

Answer. 62 degrees.

2. What is the sun's meridian altitude at London on the 21st of March?

3. What is the sun's least meridian altitude at London?

4. What is the sun's greatest meridian altitude at Cape Horn?

5. What is the sun's meridian altitude at Madras on the 20th of June?

6. What is the sun's meridian altitude at Bencoolen, on the 15th of January?

7. What is the sun's meridian altitude at Edinburgh on the following days: Dec. 21, March 21, June 21?

What is the sun's meridian altitude at the following places on the respective days?

8. Glasgow, May 1.
9. Lima, January 1.
10. Jamaica, June 21.
11. Liverpool, August 8.
12. Leipsic, October 1.
13. Naples, June 10.

PROBLEM XLII.

When it is midnight at any place in the temperate or torrid zones, to find the sun's altitude at any place (on the same meridian) in the north frigid zone, where the sun does not descend below the horizon.

RULE. Elevate the pole equal to the sun's declination for the given day; bring the place (in the frigid zone) to that rt of the brass meridian under the elevated pole, and the mber of degrees between it and the horizon will be the n's altitude.

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* The sun's meridian altitude may be found by calculation as follows:—

If the latitude of the place and the sun's declination be of the same name, *add* the latter to the *complement* of the latitude: their sum will be the sun's meridian altitude, but of a *contrary* name to the latitude. Should the sum exceed 90°, its *supplement* will be the altitude and of the *same* name with the latitude. When the latitude and declination are of different names, the latter *subtracted* from the *co-latitude* will give the sun's altitude of a *contrary* name to the latitude. If the declination exceed the co-latitude, the sun will be so many degrees *below* the horizon as are equal to the difference between them.

OR,

Elevate the north pole equal to the latitude of the place n the frigid zone; bring the sun's place in the ecliptic to he brass meridian, and set the index of the hour circle to 2; turn the globe on its axis till the index points to the other 2; and the number of degrees between the sun's place and he horizon, counted on the brass meridian, will be the sun's ltitude.

EXAMPLES. 1. What is the sun's altitude at the North ape in Lapland, when it is midnight at Alexandria in gypt on the 21st of June?

Answer. 5 degrees.

2. When it is midnight to the inhabitants of the island f Sicily on the 22nd of May, what is the sun's altitude at he north of Spitzbergen, in latitude 80° north?

3. What is the sun's altitude at the north-east of Nova embla, when it is midnight at Tobolsk, on the 15th of July?

4. What is the sun's altitude at the north of Baffin's Bay, hen it is midnight at Buenos Ayres, on the 28th of May?

PROBLEM XLIII.

To find the sun's amplitude at any place.

RULE. Elevate the pole equal to the latitude of the given place; find the sun's place in the ecliptic, and bring it to the eastern semicircle of the horizon; the number of degrees from the sun's place to the east point of the horizon will be the rising amplitude; bring the sun's place to the western semicircle of the horizon; the number of degrees from the sun's place to the west point of the horizon will be the setting amplitude.*

OR, BY THE ANALEMMA.

Proceed precisely as above directed, only using the day of the month in the analemma instead of the sun's place on the ecliptic.

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* In most globes the amplitude is marked on one of the circles of the horizon. The word amplitude will be found at the east and west points.

EXAMPLES. 1. What is the sun's amplitude at London on the 21st of June?

Answer. 39° 48′ to the north of the east, and 39° 48′ to the north of the west.

2. On what point of the compass does the sun rise and set at London on the 17th of May?

3. On what point of the compass does the sun rise and set at the Cape of Good Hope on the 21st of December?

4. On what point of the compass does the sun rise and set on the 21st of March?

5. On what point of the compass does the sun rise and set at Washington on the 21st of October?

6. On what point of the compass does the sun rise and set at Petersburg on the 18th of December?

7. On December 22nd, 1844, in latitude 31° 38′ S. and longitude 83° W., if the sun set on the S.W. point of the compass, what was the variation?

8. On the 15th of May, 1846, if the sun rose E. by N., in latitude 33° 15′ N. and longitude 18° W., what was the variation of the compass?

What is the sun's amplitude on the following days at Dublin?

9. January 1.
10. February 15.
11. May 11.
12. June 21.
13. August 8.
14. October 11.

PROBLEM XLIV.

To find the sun's azimuth and his altitude at any place, the day and hour being given.

RULE. Elevate the pole equal to the latitude of the place, and screw the quadrant of altitude on the brass meridian, over that latitude; find the sun's place in the ecliptic; bring it to the brass meridian, and set the index of the hour circle to 12; then turn the globe till the index point to the given hour; bring the graduated edge of the quadrant of altitude over the sun's place; then the number of degrees on the horizon, reckoned from the north or south point thereof to the graduated edge of the quadrant, will show the azimuth*, and the number of degrees on the quadrant cut by the sun's place will be the sun's altitude.

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* The azimuth is marked on one of the circles on the horizon.

OR, BY THE ANALEMMA.

Proceed precisely as above, only using the day of the month in the analemma instead of the sun's place in the ecliptic.

EXAMPLES. 1. What is the sun's altitude, and his azimuth from the north, at London, on the 1st of May, at ten o'clock in the morning?

Answer. The altitude is 47°, and the azimuth from the north 136°, or from the south 44°.

2. What is the sun's altitude and azimuth at Petersburg on the 13th of August, at half-past five o'clock in the morning?

3. What is the sun's azimuth and altitude at Antigua, on the 21st of June, at half-past six in the morning, and at half-past ten?*

4. At Barbadoes on the 21st of June, required the sun's azimuth and altitude at 8 minutes past 6, and at ¾ past 9 in the morning: also at ¼ past 2, and at 52 minutes past 5 in the afternoon.

5. On the 13th of August at half-past eight o'clock in the morning, at sea, in latitude 57° N. the observed azimuth of the sun was S. 40° 14′ E., what was the sun's altitude, his true azimuth, and the variation of the compass?

6. On the 14th of January, in latitude 33° 52′ S., at half past three o'clock in the afternoon, the sun's magnetic azimuth was observed to be N. 63° 51′ W.; what was the true azimuth, the variation of the compass, and the sun's altitude?

What is the sun's altitude and azimuth at the following places and times?

7. Edinburgh, June 21, 8 P.M.
8. Bristol, December 21, 9 A.M.
9. Tunis, August 8, 3 P.M.
10. Mecca, June 1, 2 P.M.

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* At all places in the torrid zone, whenever the declination of the sun exceeds the latitude of the place, and both are of the same name, the sun will appear twice in the forenoon and twice in the afternoon, on the same point of the compass, and will cause the shadow of an azimuth dial to go back several degrees. In this example, the sun's azimuth at the hours given above will be 69° from the north towards the east; and at half-past eight o'clock, the sun will appear to have the same azimuth for some time.

11. Surat, August 11, 1 P.M.
12. Tornea, July 7, 5 A.M.
13. I. of France, January 30, 7 A.M.
14. Botany Bay, May 7, 4 P.M.

PROBLEM XLV.

*The latitude of the place, day of the month, and the sun's altitude being given, to find the sun's azimuth and the hour of the day.**

RULE. Elevate the pole equal to the latitude of the place, and screw the quadrant of altitude on the brass meridian over that latitude; bring the sun's place in the ecliptic to the brass meridian, and set the index of the hour-circle to 12; turn the globe on its axis and the quadrant till the sun's place in the ecliptic coincides with the given degree of altitude on the quadrant; the index will show the time, and the azimuth will be found on the horizon, as in the preceding problem.

OR, BY THE ANALEMMA.

This problem is worked by the analemma precisely as above, only using the day of the month in the analemma instead of the sun's place in the ecliptic.

EXAMPLES. 1. At what hour of the day on the 21st of March is the sun's altitude 22¼° at London, and what is his azimuth? The observation being made in the afternoon.

Answer. The time from noon will be found to be 3 hours 30 minutes, and the azimuth 59° 1′ from the south towards the west. Had the observations been made before noon, the time from noon would have been 3½ hours, viz. it would have been 30 minutes past 8 in the morning, and the azimuth would have been 59° 1′ from the south towards the east.†

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* This problem is only a variation of the preceding; for, by the nature of spherical trigonometry, any three of the following quantities, viz. the *latitude* of the place, the *sun's declination, altitude, azimuth* or *time of the day*, being given, the rest may be found, admitting of several variations. A large collection of Astronomical problems may be found in *Keith's Trigonometry*, seventh edit. page 281., &c. These problems are useful exercises on the globes.

† The learner will observe, that the sun has the same altitude at equal distances from noon; hence it is necessary to say whether the observation be made before or after noon, otherwise the problem admits of two answers.

2. At what hour on the 9th of March is the sun's altitude 25° at London, and what is his azimuth? The observation being made in the forenoon.

3. At what hour on the 18th of May is the sun's altitude 30° at Lisbon, and what is the azimuth? The observation being made in the afternoon.

4. Walking along the side of Queen-square in London, on the 5th of August in the forenoon, I observed the shadows of the iron-rails to be exactly the same length as the rails themselves*; pray what o'clock was it, and on what point of the compass did the shadows of the rails fall?

5. In latitude 13° 30′ N., on the 21st of June, the sun had the same azimuth at two *different* times in the morning; and also in the afternoon, viz. when his altitude was 7° 17′ and 56° 55′; required the azimuth and the hours of the day. It is likewise required to find the azimuth when it is the greatest, and the hour; the altitude at that time being 35° 50′.

What will be the sun's azimuth and the hour when it has the following altitudes at the under-mentioned places, on the given days?

	Altitude.
6. Edinburgh, May 11.	25° morning.
7. Lisbon, August 1.	58° morning.
8. Cherson, June 6.	60° evening.
9. Archangel, January 7.	4° morning.
10. Owhyhee, September 20.	32° evening.
11. Aberdeen, February 11.	8° morning.
12. York, July 7.	37° evening.
13. Naples, December 21.	14° morning.
14. Medina, August 1.	62° morning.
15. Constantinople, May 11.	53° morning.

PROBLEM XLVI.

Given the latitude of the place, and the day of the month, to find at what hour the sun is due east or west.

RULE. Elevate the pole equal to the latitude of the place; find the sun's place in the ecliptic; bring it to the brass meridian, and set the index of the hour-circle to 12;

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* Vide Geographical Theorem 20, page 41.

screw the quadrant of altitude on the brass meridian, over the given latitude, and move the lower end of it to the east point of the horizon; hold the quadrant in this position, and move the globe on its axis till the sun's place comes to the graduated edge of the quadrant; the index will show the time when the sun is due east*, and at the same time from noon he will be due west.

OR, BY THE ANALEMMA.

This is exactly the same as above, only instead of bringing the sun's place to the graduated edge of the quadrant, the day of the month on the analemma must be brought to it.

EXAMPLES. 1. At what hour will the sun be due east at London on the 19th of May; at what hour will he be due west; and what will his altitude be at these times?

Answer. The time from 12, when the sun is due east, is 4 hours 54 minutes; hence the sun is due east at 6 minutes past 7 o'clock in the morning, and due west at 54 minutes past 4 in the afternoon; the sun's altitude will be found at the same time, as in Problem XLIV. In this example it is 25° 26′.

2. At what hours will the sun be due east and west at London on the 21st of June, and on the 21st of December; and what will be his altitude above the horizon on the 21st of June?

3. Find at what hours the sun will be due east and west, not only at London, but at every place on the surface of the globe, on the 21st of March and on the 23rd of September.

4. At what hours is the sun due east and west at Buenos Ayres on the 21st of December?

PROBLEM XLVII.

Given the sun's meridian altitude and the day of the month, to find the latitude of the place.

RULE. Find the sun's place in the ecliptic, and bring it to the brass meridian; then, if the sun was south[*] of the observer when the altitude was taken, count the number of degrees from the sun's place on the brass meridian towards the south point of the horizon, and mark where the reckoning ends; bring this mark to the south point of the horizon, and the elevation of the north pole will show the latitude. If the sun was north of the observer when the altitude was taken, the degrees must be counted in a similar manner, from the sun's place towards the north point of the horizon, and the elevation of the south pole will show the latitude.

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* If the latitude be north, and the sun's declination be south, he will be due east and west when he is below the horizon; and the same thing will happen if the latitude be south when the declination is north. Examples exercising these cases are useless; however, they are easily solved, if we consider that, when the sun is due east below the horizon at any time, the opposite point of the ecliptic will be due west above the horizon; therefore, instead of bringing the lower edge of the quadrant to the east of the horizon, bring it to the west, and, instead of using the sun's place, make use of a point in the ecliptic diametrically opposite.

OR, WITHOUT A GLOBE.

Subtract the sun's altitude from 90 degrees; the remainder is the zenith distance. If the sun be south when his altitude is taken, call the zenith distance north; but, if north, call it south; find the sun's declination in an ephemeris[†] or a table of the sun's declination[‡], and mark whether it be north or south; then, if the zenith distance and declination have the same name, their sum is the latitude: but, if they have contrary names, their difference is the latitude, and it is always of the same name with the greater of the two quantities.

EXAMPLES. On the 10th of May, 1842, I observed the sun's meridian altitude to be 50°, and it was south of me at that time; required the latitude of the place.

Answer. 57° 35′ north.

By calculation.

90° 0′
50 0 *S.*, sun's altitude at noon.

40 0 *N.*, the zenith's distance.
17 35 *N.*, the sun's declination, 10th May, 1842.

57 35 *N.*, the latitude sought.

2. On the 10th of May, 1842, the sun's meridian altitude was observed to be 50°, and it was north of the observer at that time; required the latitude of the place.

Answer. 22° 25′ south.

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[*] It is necessary to state whether the sun be to the north or south of the observer at noon, otherwise the problem is unlimited.

[†] The most convenient is the Nautical Almanac, or White's Ephemeris; see the note page 37.

[‡] Page 270.

By calculation.

90° 0′
50 0 *N.*, sun's altitude at noon.

40 0 *S.*, the zenith's distance.
17 35 *N.*, the sun's declination, 10th May, 1842.

22 25 *S.*, the latitude sought.

3. On the 5th of August, 1842, the sun's meridian altitude was observed to be 74° 30′ north of the observer; what was the latitude?

4. On the 19th of November, 1842, the sun's meridian altitude was observed to be 40° south of the observer; what was the latitude?

5. At a certain place, where the clocks are two hours faster than at London, the sun's meridian altitude was observed to be 30° to the south of the observer on the 21st of March; required the place.

6. At a place where the clocks are five hours slower than at London, the sun's meridian altitude was observed to be 60° to the south of the observer on the 16th of April, 1843; required the place.

What is the latitude of those places at which the sun has the following meridian altitudes on the given days?

7. 40° S., August 1st.
8. 70° S., January 2nd.
9. 49° N., August 1.
10. 38° S., April 11th.
11. 57° S., September 4th.
12. 83° N., September 23rd.
13. 37° N., December 10th.

14. At a place where the clocks are 4 hours slower than at London, the sun's meridian altitude on November 22nd was 67° S.; required the place.

15. What place is that where the clocks are 3 hours faster than that at Jerusalem, where the sun's meridian altitude on April 25th is 90°?

Problem XLVIII.

The length of the longest day at any place, not within the polar circles, being given, to find the latitude of that place.

Rule. Bring the first point of Cancer or Capricorn to the brass meridian (according as the place is on the north or south side of the equator), and set the index of the hour-circle to 12; turn the globe westward on its axis till the index of the hour circle has passed over as many hours as are equal to half the length of the day; elevate or depress the pole till the sun's place (viz. Cancer or Capricorn) comes to the horizon; then the elevation of the pole will show the latitude.

NOTE. This problem will answer for any day in the year, as well as the longest day, by bringing the sun's place to the brass meridian and proceeding as above.

OR, Bring the middle of the analemma to the brass meridian, and set the index of the hour-circle to 12; turn the globe westward on its axis till the index has passed over as many hours as are equal to half the length of the day; elevate or depress the pole till the day of the month coincides with the horizon, then the elevation of the pole will show the latitude.

EXAMPLES. 1. In what degree of north latitude, and at what places is the length of the longest day 16½ hours?

Answer. In latitude 52°, and all places situated on, or near that parallel of latitude, have the same length of the day.

2. In what degree of south latitude, and at what places is the longest day 14 hours?

3. In what degree of north latitude is the length of the longest day three times the length of the shortest night?

4. There is a town in Norway where the longest day is five times the length of the shortest night; pray what is the name of the town?

5. In what latitude north does the sun set at seven o'clock on the 5th of April?

6. In what latitude south does the sun rise at five o'clock on the 25th of November?

7. In what latitude north is the 20th of May 16 hours long?

8. In what latitude north is the night of the 15th of August 10 hours long?

In what latitudes is January 20th of the following lengths?

9. 6 hours.	11. 10 hours.	13. 16 hours.
10. 8 hours.	12. 12 hours.	14. 18 hours.

PROBLEM XLIX.

The latitude of a place and the day of the month being given, to find how much the sun's declination must vary to make the day an hour longer or shorter than the given day.

RULE. Find the sun's declination for the given day, and *elevate* the pole to that declination; bring the given place to the brass meridian, and set the index of the hour-circle to 12: turn the globe eastward on its axis till the given place comes to the horizon, and observe the hour on the index. Then, if the days be increasing, continue the motion of the globe eastward till the index has passed over another half hour, and raise or depress the pole till the place comes again into the horizon; the elevation of the pole will show the sun's declination when the day is an hour longer than the given day; but, if the days be decreasing, after the place is brought to the eastern part of the horizon, turn the globe westward till the index has passed over half an hour, then raise or depress the pole till the place comes a second time into the horizon, the last elevation of the pole will show the sun's declination when the day is an hour shorter than the given day.

OR,

Elevate the pole to the latitude of the place, find the sun's place in the ecliptic, bring it to the brass meridian, and set the index of the hour-circle to 12; turn the globe westward on its axis till the sun's place comes to the horizon, and observe the hour by the index; then, if the days be increasing, continue the motion of the globe westward till the index has passed over another half-hour, and observe what point of the ecliptic is cut by the horizon; that point will show the sun's place when the day is an hour longer than the given day, whence the declination is readily found; but, if the days be decreasing, turn the globe eastward till the index has passed over half an hour, and observe what point of the ecliptic is cut by the horizon; that point will show the sun's place when the day is an hour shorter than the given day.

OR, BY THE ANALEMMA.

Proceed exactly the same as above, only, instead of bringing the sun's place to the brass meridian, bring the analemma there, and instead of the sun's place, use the day of the month on the analemma.

EXAMPLES. How much must the sun's declination vary that the day at London may be increased one hour from the 24th of February?

Answer. On the 24th of February the sun's declination is 9° 38′ south, and the sun sets at a quarter past five; when the sun sets at three quarters past five, his declination will be found to be about 4¼° south, answering to the 10th of March; hence the declination has decreased 5° 23′, and the days have increased 1 hour in 14 days.

2. How much must the sun's declination vary that the day at London may decrease *one* hour in length from the 26th of July?

Answer. The sun's declination on the 26th of July is 19° 38′ north, and the sun sets at 49 min. past seven; when the sun sets at 19 min. past seven, his declination will be found to be 14° 43′ north, answering to the 13th of August: hence the declination has decreased 5° 55′, and the days have decreased *one* hour in 18 days.

3. How much must the sun's declination vary from the 5th of April, that the day at Petersburgh may increase *one* hour?

4. How much must the sun's declination vary, from the 4th of October, that the day at Stockholm may decrease *one* hour?

5. What is the difference in the sun's declination, when he rises at seven o'clock at Petersburgh, and when he sets at nine?

PROBLEM L.

To find the sun's right ascension, oblique ascension, oblique descension, ascensional difference, and time of rising and setting at any place.

This problem is best done by the celestial globe.

RULE. Find the sun's place in the ecliptic, and bring it to the brass meridian; the degree on the equator cut by the graduated edge of the brass meridian, reckoning from the point Aries eastward, will be the sun's right ascension.

Elevate the pole equal to the latitude of the place, bring the sun's place in the ecliptic to the eastern part of the horizon*, and the degree on the equator cut by the horizon, reckoning from the point Aries eastward, will be the sun's oblique ascension. Bring the sun's place in the ecliptic to the western part of the horizon*, and the degree on the equator cut by the horizon, reckoning from the point Aries eastward, will be the sun's oblique descension.

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* The rising amplitude may be seen at the same time. See Problem XLIII.

Find the difference between the sun's right and oblique ascension; or, which is the same thing, the difference between the right ascension and oblique descension, and turn this difference into time by multiplying by 4 †: then, if the sun's declination and the latitude of the place be both of the same name, viz. both north or both south, the sun rises before six and sets after six, by a space of time equal to the ascensional difference; but if the sun's declination and the latitude be of contrary names, viz. the one north and the other south, the sun rises after six and sets before six.

EXAMPLES. 1. Required the sun's right ascension, oblique ascension, oblique descension, ascensional difference, and time of rising and setting at London, on the 15th of April?

Answer. The right ascension is 23° 30′, the oblique ascension is 9° 45′, the ascensional difference (23 30′—9° 45′=) 13° 45′, or 55 minutes of time; consequently the sun rises 55 minutes before 6, or 5 min. past 5, and sets 55 min. past 6. The oblique descension is 37° 15′; consequently the descensional difference is (37° 15′ — 23° 30′=) 13° 45′, the same as the ascensional difference.

2. What are the sun's right ascension, oblique ascension, and oblique descension, on the 27th of October at London? what is the ascensional difference, and at what time does the sun rise and set?

3. What are the sun's right ascension, declination, oblique ascension, rising amplitude, oblique descension, and setting amplitude, at London, on the 1st of May? what is the ascensional difference, and at what time does the sun rise and set?

4. What are the sun's right ascension, declination, oblique ascension, rising amplitude, oblique descension, and setting amplitude at Petersburgh, on the 21st of June? what is the ascensional difference, and at what time does the sun rise and set?

5. What are the sun's right ascension, declination, oblique ascension, rising amplitude, oblique descension, and setting amplitude at Alexandria, on the 21st of December? what is

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* The setting amplitude may here be seen. Vide Prob. XLIII.

† See Problem XVIII.

the ascensional difference, and at what time does the sun rise and set?

What are the sun's right ascension, oblique ascension, declination, oblique descension, ascensional difference, and amplitude at the following places and times?

6. Calcutta, February 11.
7. Cracow, August 22.
8. New York, October 12.
9. Montreal, December 1.
10. Havanna, July 11.
11. Monte Video, April 20.
12. Lima, August 1.

PROBLEM LI.

Given the day of the month and the sun's amplitude, to find the latitude of the place of observation.

RULE. Find the sun's place in the ecliptic, and bring it to the eastern or western part of the horizon (according as the eastern or western amplitude is given); elevate or depress the pole till the sun's place coincides with the given amplitude on the horizon, then the elevation of the pole will show the latitude.

EXAMPLES. 1. The sun's amplitude was observed to be 39° 48′ from the east towards the north, on the 21st of June; required the latitude of the place.

Answer. 51° 32′ north.*

2. The sun's amplitude was observed to be 15° 30′ from the east towards the north, at the same time his declination was 15° 30′: required the latitude.

3. On the 29th of May, when the sun's declination was 21° 30′ north, his rising amplitude was known to be 22° northward of the east: required the latitude.

4. When the sun's declination was 2° north, his rising amplitude was 4° north of the east: required the latitude.

What are the latitudes of the places at which the sun has the following amplitudes on the given days?

5. July 7. 43 N.E.
6. Aug. 9. 38 N.E.
7. Sept. 29. 4 S.E.
8. Oct. 19. 14 S.E.
9. Dec. 11. 60 S.E.
10. May 20. 60 N.E.
11. June 21. 80 N.E.
12. Dec. 21. 80 S.E.

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* See *Keith's Trigonometry*, fourth edition, page 285.

PROBLEM LII.

Given two observed altitudes of the sun, the time elapsed between them, and the sun's declination, to find the latitude.[*]

RULE. Take a number of degrees equal to the sun's declination from the equator with a pair of compasses, and apply the same number of degrees upon the meridian passing through Libra[†] from the equator northward or southward, and mark where they extend to; turn the elapsed time into degrees[‡], and count those degrees upon the equator from the meridian passing through Libra; bring that point of the equator where the reckoning ends to the graduated edge of the brass meridian, and set off the sun's declination from that point along the edge of the meridian, the same way as before; then take the complement of the first altitude from the equator in your compasses, and with one foot in the sun's declination, and a fine pencil in the other foot, describe an arc; take the complement of the second altitude in a similar manner from the equator, and with one foot of the compasses fixed in the second point of the sun's declination, cross the former arc: the point of intersection brought to that part of the brass meridian which is numbered from the equator towards the poles, will stand under the degree of latitude sought.

EXAMPLES. 1. Suppose on the 4th of June, 1839, in north latitude, the sun's altitude at 29 minutes past 10 in the forenoon, to be 65° 24′, and at 31 minutes past 12, 74° 8′: required the latitude.

Answer. The sun's declination is 22° 22′ north, the elapsed time two hours two min. answering to 30° 30′; the complement of the first altitude 24° 36′, the complement of the second altitude 15° 52′, and the latitude sought 36° 57′ north.

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[*] If the teacher should think the drawing circles on the globe with a pair of compasses exceptionable, this problem may be omitted.

[†] Any meridian will answer the purpose as well as that which passes through Libra; on Adams' and on Cary's globes this meridian is divided like the brass meridian. If Newton's globes be used, take the meridian passing through Cancer.

[‡] *See the* method of turning time into degrees. Prob. XIX.

2. *Given the sun's declination 19° 39′ north, his altitude in the forenoon 38° 19′, and, at the end of one hour and a half, the same morning, the altitude was 50° 25′: required the latitude of the place, supposing it to be north.

3. When the sun's declination was 22° 40′ north, his altitude at 10 h. 54 m. in the forenoon was 53° 29′, and at 1 h. 17 m. in the afternoon it was 52° 48′; required the latitude of the place of observation, supposing it to be north.

4. In north latitude, when the sun's declination was 22° 23′ south, the sun's altitude in the afternoon was observed to be 14° 46′, and after 1 h. 22 m. had elapsed, his altitude was 8° 27′; required the latitude.

PROBLEM LIII.

The day and hour being given when a solar eclipse will happen, to find where it will be visible.

RULE. Find the sun's declination, and elevate the pole agreeably to that declination; bring the place at which the hour is given to the brass meridian, and set the index to the given time, turn the globe till the index points to 12 at noon, and under the degree of the sun's declination on the brass meridian you will find the place on the globe where the sun will be vertically eclipsed†: at all places within 70 degrees of this place, the eclipse *may*‡ be visible, especially if it be a total eclipse.

EXAMPLE. On the 9th of October, 1847, at 29 min. past seven o'clock in the morning at London, there will be an eclipse of the sun, where will it be visible, supposing the moon's penumbral shadow should extend northward 70 degrees from the place where the sun will be vertically eclipsed?

Answer. To the whole of Arabia, Persia, Hindoostan, &c. For more examples consult the Table of Eclipses following the next problem.

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* A great variety of examples accurately calculated by a general rule, without an assumed latitude, may be seen in *Keith's Trigonometry*, seventh edition, 323, &c.

† The effect of parallax is so great, that an eclipse may not be visible even where the sun is vertical.

‡ When the moon is exactly in the node, and when the axes of the moon's shadow and penumbra pass through the centre of the earth, the breadth of the earth's surface under the penumbral shadow is 70° 20′: but the breadth of this shadow is variable; and if it be not accurately determined by calculation, it is impossible to tell by the globe to what extent an eclipse of the sun will be visible.

PROBLEM LIV.

The day and hour being given when a lunar eclipse will happen, to find where it will be visible.

RULE. Find the sun's declination for the given day, and elevate the *opposite* pole equal to the declination. Bring the given place to the brass meridian, and set the index to the given hour, and then turn the globe till the index points to 12 at *midnight*, and to all places then above the horizon the lunar eclipse will be visible.

EXAMPLE. On the 31st of May, 1844, at 50 minutes past ten in the evening at London, there will be an eclipse of the moon; where will it be visible?

Answer. It will be visible to the whole of Europe, Africa, and the greater part of the continent of Asia. For more examples see the following Table of Eclipses, and pages 324 and 325.

NOTE. The substance of the following Table of Eclipses was extracted from *Dr. Hutton*'s translation of *Montucla*'s edition of *Osanum's Mathematical and Physical Recreations*, published by Mr. Kearsley in Fleet-street. These eclipses were originally calculated by M. Pingré, a member of the Academy of Sciences, and published in *L'Art de vérifier les Dates.* In classing these tables the arrangement of Mr. Ferguson has been followed; see page 267 of his astronomy, where a catalogue of the visible eclipses is given from 1700 to 1800, taken from *L'Art de vérifier les Dates.* It may be necessary to inform the learner, that the times of these eclipses, as calculated by M. Pingré, are not perfectly accurate, and were only designed to show nearly the time when an eclipse may be expected to happen. The limits where these eclipses are visible are generally from the tropic of Cancer in Africa, to the northern extremity of Lapland, and from the 5th degree of north latitude in Asia, to the north polar circle; though some few of them are visible beyond the pole. In longitude, the limits are the fifth and 155th meridians, supposing the 20th to pass through Paris: hence it appears that they are calculated for the meridian of Ferro; which will make their limits from London to be from 12° 46′ west long. to 137° 14′ east. M. Pingré says, that an eclipse of the sun is visible from 32° to 64° north, and as far south of the place where it is central. In the following table the moon is represented by ☽, the sun by ☉, T stands for total, P for partial, M for morning, and A for afternoon, the rest is obvious.

Years.			Months and Days.	Time.	
1823	☽	T	Jan. 26	5½	A
——	☼		Feb. 11	3	M
——	☼		July 8	6½	M
——	☽	T	July 23	3½	M
1824	☽	P	Jan. 16	9	M
——	☼		June 26	11½	A
——	☽	P	July 11	4½	M
——	☼		Dec. 20	11	M
1825	☽	P	June 1	0½	M
——	☼		June 16	0½	A
——	☽	P	Nov. 25	4½	A
1826	☽	T	May 21	3½	A
——	☽	T	Nov. 14	4½	A
——	☼		Nov. 29	11½	M
1827	☼		April 26	3½	M
——	☽	P	May 11	8¾	M
——	☽	P	Nov. 3	5	A
1828	☼		April 14	9¾	M
——	☼		Oct. 9	0½	M
1829	☽	P	March 20	2	A
——	☽	P	Sept. 13	7	M
——	☼		Sept. 28	2½	M
1830	☼		Feb. 23	5	M
——	☽	T	March 9	2	A
——	☽	T	Sept. 2	11	A
1831	☽	P	Feb. 26	5	A
——	☽	P	Aug. 23	10½	M
1832	☼		July 27	2½	A
1833	☽	P	Jan 6	8	M
——	☽	P	July 2	1	M
——	☼		July 17	7	M
——	☽	T	Dec. 26	10	A
1834	☽	T	June 21	8½	M
——	☽	P	Dec. 16	5¼	M
1835	☼		May 27	1½	A
——	☽	P	June 10	11	A
1835	☼		Nov. 20	11	M
1836	☽	P	May 1	8½	M
——	☼		May 15	2½	A
1836	☽	P	Oct. 24	1¾	A
1837	☽	T	April 20	9	A
——	☼		May 4	7½	A
——	☽	T	Oct. 13	11½	A
1838	☽	P	April 10	2¼	M
——	☽	P	Oct. 3	3	A
1839	☼		March 15	2½	A
——	☼		Sept. 7	10½	A
1840	☽	P	Feb. 17	2	A
——	☼		March 4	4	M
——	☽	P	Aug. 13	7½	M
1841	☽	T	Feb. 6	2½	M
——	☼		Feb. 21	11	M
——	☼		July 18	2	A
——	☽	T	Aug. 2	10	M
1842	☽	P	Jan. 26	6	A
——	☼		July 8	7	M
——	☽	P	July 22	11	M
1843	☽	P	June 12	8	M
——	☽	P	Dec. 7	0½	M
——	☼		Dec. 21	5½	M
1844	☽	T	May 31	11	A
——	☽	T	Nov. 25	0¼	M
1845	☼		May 6	8½	M
——	☽	T	May 21	4½	A
——	☽	P	Nov. 14	1	M
1846	☼		April 25	5¹	A
——	☼		Oct. 20	8¹	M
1847	☽	P	March 31	9½	A
——	☼		Sept. 24	3	A
——	☼		Oct. 9	7½	M
1848	☽	T	March 19	9½	A
——	☽	T	Sept. 13	6½	M
——	☼		Sept. 27	10	M
1849	☼		Feb. 23	1½	M
——	☽	P	March 9	1	M
——	☽	P	Sept. 2	5½	A
1850	☼		Feb. 12	6½	M
——	☼		Aug. 7	10	[illegible]

Years.			Months and Days.	Time.		Years.			Months and Days.	Time.	
1851	☽	P	Jan. 17	5	A	1865	☉		Oct. 19	5	A
——	☽	P	July 13	7½	M	1866	☉		March 16	10	A
——	☉		July 28	2½	A	——	☽	T	March 31	5	M
1852	☽	T	Jan. 7	6½	M	——	☽	T	Sept. 24	2½	A
——	☽	T	July 1	3¾	A	——	☉		Oct. 8	5¼	A
——	☉		Dec. 11	4	M	1867	☉		March 6	10	M
——	☽	P	Dec. 26	1	A	——	☽	P	March 20	9	M
1853	☽	P	June 21	6	M	——	☽	P	Sept. 14	1	M
1854	☽	P	May 12	4	A	1868	☉		Feb. 23	2½	A
——	☽	P	Nov. 4	9½	A	——	☉		Aug. 18	5½	M
1855	☽	T	May 2	4½	M	1869	☽	P	Jan. 28	1¾	M
——	☉		May 16	2½	M	——	☽	P	July 23	2	A
——	☽	T	Oct. 25	8	M	——	☉		Aug. 7	10	A
1856	☽	P	April 20	9½	M	1870	☽	T	Jan. 17	3	A
——	☉		Sept. 29	4	M	——	☽	T	July 12	11	A
——	☽	P	Oct. 13	11½	A	——	☉		Dec. 22	0¾	A
1857	☉		Sept. 18	6	M	1871	☽	P	Jan. 6	9½	A
1858	☽	P	Feb. 27	10¼	A	——	☉		July 18	2½	M
——	☉		March 15	0½	A	——	☽	P	July 2	1½	A
——	☽	P	Aug. 24	2½	A	——	☉		Dec. 12	4½	M
1859	☽	T	Feb. 17	11	M	1872	☽	P	May 22	11½	A
——	☉		July 29	9½	A	——	☉		June 6	3½	M
——	☽	T	Aug. 13	4½	A	——	☽	P	Nov. 15	5¾	M
1860	☽	P	Feb. 7	2½	M	1873	☽	T	May 12	11½	M
——	☉		July 18	2	A	——	☉		May 26	9½	M
——	☽	P	Aug. 1	5½	A	——	☽	T	Nov. 4	4½	A
1861	☉		Jan. 11	3½	M	1874	☽	P	May 1	4½	A
——	☉		July 8	2	M	——	☉		Oct. 10	11½	M
——	☽	P	Dec. 17	8½	M	——	☽	P	Oct. 25	8	M
——	☉		Dec. 31	2½	A	1875	☉		April 6	7	M
1862	☽	T	June 12	6¾	M	——	☉		Sept. 29	1½	A
——	☽	T	Dec. 6	8	M	1876	☽	P	March 10	6½	M
——	☉		Dec. 21	5½	M	——	☽	P	Sept. 3	9½	A
1863	☉		May 17	5	A	1877	☽	T	Feb. 27	7½	A
——	☽	T	June 2	0	M	——	☉		March 15	3	M
——	☽	P	Nov. 25	9	M	——	☉		Aug. 9	5	M
1864	☉		May 6	0¾	M	——	☽	T	Aug. 23	11½	A
1865	☽	P	April 11	5	M	1878	☽	P	Feb. 17	11½	M
——	☽	P	Oct. 4	11	A	——	☉		July 29	9½	A

			Months and Days.	Time.		Years.			Months and Days.	Time.	
8	☽	P	Aug. 13	0½	M	1890	☉		June 17	10	M
9	☉		Jan. 22	Merid.		——	☽	P	Nov. 26	2	A
–	☉		July 19	9	M	1891	☽	T	May 23	7	A
–	☽	P	Dec. 28	4½	A	——	☉		June 6	4½	A
0	☉		Jan. 11	11	A	——	☽	T	Nov. 16	0¾	M
–	☽	T	June 22	2	A	1892	☽	P	May 11	11½	A
–	☽	T	Dec. 16	4	A	——	☽	T	Nov. 4	4½	A
–	☉		Dec. 31	2	A	1893	☉		April 16	3	A
1	☉		May 28	0	M	1894	☽	P	March 21	2½	A
–	☽	T	June 12	7¼	M	——	☉		April 6	4½	M
–	☽	P	Dec. 5	5½	A	——	☽	P	Sept. 15	4¾	M
2	☉		May 17	8	M	——	☉		Sept. 29	5½	M
–	☉		Nov. 11	0	M	1895	☽	T	March 11	4	M
3	☽	P	April 22	Merid.		——	☉		March 26	10	M
–	☽	P	Oct. 16	7½	M	——	☉		Aug. 20	0½	A
–	☉		Oct. 31	0½	M	——	☽	T	Sept. 4	6	M
4	☉		March 27	6	M	1896	☽	P	Feb. 28	8	A
–	☽	T	April 10	Merid.		——	☉		Aug. 9	4½	M
–	☽	T	Oct. 4	10½	A	——	☽	P	Aug. 23	7	M
–	☉		Oct. 19	1	M	1897	No visible Eclipse.				
5	☽	P	March 30	5	A	1898	☽	P	Jan. 8	0½	M
–	☽	P	Sept. 24	8½	M	——	☉		Jan. 22	8	M
6	☉		Aug. 29	1½	A	——	☽	P	July 3	9½	A
7	☽	P	Feb. 8	10½	M	——	☽	T	Dec. 27	12	A
–	☽	P	Aug. 3	9	A	1899	☉		Jan. 11	11	A
–	☉		Aug. 19	6	M	——	☉		June 8	7	M
3	☽	T	Jan. 28	11½	A	——	☽	T	June 23	2½	A
–	☽	T	July 23	6	M	——	☽	P	Dec. 17	1½	M
)	☽	P	Jan. 17	5½	M	1900	☉		May 28	3¼	A
–	☽	P	July 12	9	A	——	☽	P	June 13	4	M
–	☉		Dec. 22	1	A	——	☉		Nov. 22	8	M
)	☽	P	June 23	6	M						

PROBLEM LV.

To find the time of the year when the Sun and Moon will be liable to be eclipsed.

RULE 1. Find the place of the moon's nodes, the time of *new moon*, and the sun's longitude at that time, by an ephemeris, as the Nautical Almanac: then if the sun be within 17 degrees of the moon's node, there will be an eclipse of the sun.

2. Find the place of the moon's nodes, the time of full moon, and the sun's longitude at that time, by an ephemeris: then, if the sun's longitude be in opposition to that of the moon, and the moon's longitude be within 12 degrees of her node, there will be an eclipse of the moon.

OR, WITHOUT THE EPHEMERIS.

The mean annual variation of the moon's node, which is retrograde, is 19° 19′·7, or more nearly 19° 19′ 42″·316, and the daily motion 3′·18, the place of the ascending node for the 1st of January, 1840, being 339° 36′·4, its place for any other time may therefore be found.

For example, on the 1st of January, 1841, the ☾'s ascending node was, according to the rule, 320° 16′·7, viz. 339° 36′·4 – 19° 19′·7; but because 1840 was leap year and consisted of 366 days, 3′·18 must be deducted, for the extra day, from 320° 16′·7 making 320° 13′·5, the same as given in the Nautical Almanac, p. 266.

On the 1st of Jan. 1845, the ☽'s ascending node will be 339° 36′·4, *minus* 5 times 19° 19′·7, together with *twice* 3′·18 for leap years, in 1840 and 1844, making 339° 36′·4 – 96° 44′·9 = 242° 51′·5, the ☽'s ascending node, the descending node being opposite to it must be 242° 51′·5 – 180° = 62° 51′·5.

The time of *new moon* may be found as directed at page 234., and the sun's longitude is the sun's place in the ecliptic.* The rest may be found as above.

EXAMPLES. 1. On the 31st of May, 1844, there will be a full moon, at which time the place of the moon's ascending node will be 254° 14′, and her longitude 250° or 10° in ♐, and the sun's longitude 71°; will an eclipse of the moon happen at that time?

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* The moon's longitude may be found thus: Multiply 12° 11 26″·4 by the moon's age (*see* p. 233.), the product will give the number of degrees by which the moon's longitude exceeds that of the sun.

Answer. Here the sun's longitude being in opposition to that of the moon's, and the moon's longitude within 12 degrees of the moon's node, there will be an eclipse of the moon. — When the moon is in one of her nodes at the time of full moon, the sun is in the other node, and the earth is directly between them.

2. There was a new moon on the 8th of July, 1842, at which time the place of the moon's ascending node was 290° 43′, and opposite node 110° 43′, her longitude was 105° 36′, and the sun's longitude 106° 55′; was there an eclipse of the sun at that time?

3. There was a full moon on the 6th of December, 1843, at which time the place of the moon's node was 263° 34′, and her longitude 74°, the sun's longitude 254° 16′; was there an eclipse of the moon at that time?

4. On the 24th of November, 1844, there was a full moon, at which time the place of the moon's node was 244° 39′, her opposite node 64° 39′, and longitude 62½°, and the sun's longitude 242° 22′; was there an eclipse of the moon on that day?

5. On the 30th of October, 1845, there was a new moon, at which time the place of the moon's ascending node was 226° 51′, her longitude at noon 224° 37′, and latitude 0° 11′ S., and the sun's longitude 217° 57′, lat. 0°; was there an eclipse of the sun on that day?

PROBLEM LVI.

To explain the phenomenon of the harvest moon.

DEFINITION 1. The harvest moon, in north latitude, is the full moon which happens at, or near, the time of the autumnal equinox; for, to the inhabitants of north latitude, whenever the moon is in Pisces or Aries (and she is in these signs twelves times in a year), there is very little difference between her times of rising for several nights together, because her orbit is at these times nearly parallel to the horizon. This peculiar rising of the moon passes unobserved at all other times of the year except in September and October; for there never can be a full moon except the sun be directly opposite to the moon; and as this particular rising of the moon can only happen when the moon is in ♓ Pisces or

♈ Aries, the sun must necessarily be either in ♍ Virgo or ♎ Libra at that time, and these signs answer to the months of September and October.

Definition 2. The harvest moon, in south latitude, is the full moon which happens at, or near, the time of the vernal equinox; for, to the inhabitants of south latitude, whenever the moon is in ♍ Virgo or ♎ Libra (and she is in these signs twelve times in a year), her orbit is nearly parallel to the horizon: but when the full moon happens in ♍ Virgo or ♎ Libra, the sun must be either in ♓ Pisces or ♈ Aries. Hence it appears that the harvest moons are just as regular in south latitude as they are in north latitude, only they happen at contrary times of the year.

Rule for performing the problem.—1. *For north latitude.* Elevate the north pole to the latitude of the place, put a patch or make a mark in the ecliptic on the point Aries, and upon every twelve* degrees preceding and following that point, till there be ten or eleven marks; bring that mark which is the nearest to Pisces to the eastern edge of the horizon, and set the index to 12; turn the globe westward till the other marks successively come to the horizon, and observe the hours passed over by the index; the intervals of time between the marks coming to the horizon will show the diurnal difference of time between the moon's rising. If these marks be brought to the western edge of the horizon in the same manner, you will see the diurnal difference of time between the moon's setting: for, when there is the smallest difference between the times of the moon's rising†, there will be the greatest difference between the times of her setting; and, on the contrary, when there is the greatest difference between the times of the moon's rising, there will be the least difference between the times of her setting.

Note. As the moon's nodes vary their position and form a complete revolution in about nineteen years, there will be a regular period of all the varieties which can happen in the rising and setting of the moon during that time. The following table (extracted from Ferguson's Astronomy) shows in what years the harvest moons are the least and most beneficial, with regard to the times of their rising, from 1823 to 1860. The columns of years under the letter L are those in which the harvest moons are least beneficial, because they fall about the descending node; and those under M are the most beneficial, because they fall about the ascending node.

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* The reason why you mark every 12 degrees is, that the moon gains 12° 11′ 26″·4 of the sun in the ecliptic every day (see note, p. 102.).

† At London, when the moon rises in the point Aries, the ecliptic at that point makes an angle of only 15 degrees with the horizon; but when she sets in the point Aries, it makes an angle of 62 degrees: and, when the moon rises in the point Libra, the ecliptic at that point makes an angle of 62 degrees with the horizon; but, when she sets in the point Libra, it only makes an angle of 15 degrees with the horizon.

L	L	L	L	M	M	M	M
1826	1831	1845	1849	1823	1837	1842	1856
1827	1832	1846	1850	1824	1838	1843	1857
1828	1833	1847	1851	1825	1839	1853	1858
1829	1834	1848	1852	1835	1840	1854	1859
1830	1844			1836	1841	1855	1860

2. *For south latitude.* Elevate the south pole to the latitude of the place, put a patch or make a mark on the ecliptic on the point Libra, and upon every twelve degrees preceding and following that point, till there be ten or eleven marks; bring that mark which is the nearest to Virgo, to the eastern edge of the horizon, and set the index to 12; turn the globe westward till the other marks successively come to the horizon, and observe the hours passed over by the index; the intervals of time between the marks coming to the horizon will be the diurnal difference of time between the moon's rising, &c. as in the foregoing part of the problem.*

PROBLEM LVII.

The day and hour of an eclipse of any one of the satellites of Jupiter being given, to find upon the globe all those places where it will be visible.

RULE. Find the sun's declination for the given day, and elevate the pole to that declination; bring the place at which the hour is given to the brass meridian, and set the index to the given hour; and then turn it till the index point to 12 at noon; fix the globe in this position: THEN,

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* This solution is on a supposition that the moon keeps constantly in the ecliptic, which is sufficiently accurate for illustrating the problem. Otherwise the latitude and longitude of the moon, or her right ascension and declination, may be taken from the Ephemeris, at the time of full moon, and a few days preceding and following it; her place will be then truly marked on the globe.

1. *If Jupiter rise after the sun*[*], that is, if he be an evening star, draw a line along the *eastern edge of the horizon* with a black lead pencil: this line will pass over all places on the earth where the sun is setting at the given hour; turn the globe westward on its axis till as many degrees of the equator have passed under the brass meridian as are equal to the difference between the sun's and Jupiter's right ascension; keep the globe from revolving on its axis, and elevate the pole as many degrees above the horizon as are equal to Jupiter's declination, then draw another line with a pencil along the eastern edge of the horizon: the eclipse will be visible to every place between these lines, viz. from the time of the sun's setting to the time of Jupiter's setting.

2. *If Jupiter rise before the sun*[†], that is, if he be a morning star, draw a line along the *western edge of the horizon* with a black lead pencil: this line will pass over all places of the earth where the sun is rising at the given hour; turn the globe eastward on its axis till as many degrees of the equator have passed under the brass meridian as are equal to the difference between the sun's and Jupiter's right ascension; keep the globe from revolving on its axis, and elevate the pole as many degrees above the horizon as are equal to Jupiter's declination; then draw another line with a pencil along the western edge of the horizon: the eclipse will be visible to every place between these lines, viz. from the time of Jupiter's rising to the time of the sun's rising.

EXAMPLES. 1. On the 27th of August, 1845, there will be an immersion of the first satellite of Jupiter at 21 m. 18 sec. past eleven o'clock in the evening at Greenwich; where will it be visible? Jupiter's right ascension at that time will be 2 hrs. 35 m., and longitude 41° 10′, and his declination 13° 48′ N., the sun's right ascension 10 hrs. 24 m., and longitude 152° 5′.

Answer. In this example, the longitude of the sun exceeds the longitude of Jupiter, therefore Jupiter will be to the west of the sun and be morning star, but will also, owing to his position, be seen late in the vening.

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[*] Jupiter rises and sets after the sun, and is an evening star unless too near the sun, when he is to the east of the sun; his longitude at that time being generally greater than the sun's longitude.

[†] Jupiter rises before the sun, and is a morning star when he is west of the sun; his longitude at that time being generally less than the sun's longitude.

If Jupiter's longitude in the ecliptic be brought to the brass meridian, is place will stand under the degree of his declination*; and his right scension will be found on the equator, reckoning from Aries. This clipse will be visible at Greenwich to the whole of Europe, the greater art of Africa, Madagascar, Persia, Hindostan, &c.

2. On the 21st of September, 1843, at 44 min. past eight 'clock in the evening, at Greenwich, there was an emersion f the first satellite of Jupiter; where was the eclipse viible? Jupiter's right ascension was 21 h. 25 m. at that ime, and longitude about 10 signs 19° 10′, and his decliation 16° 23′ south.

3. On the 18th of November, 1844, at 14 m. 25 sec. past even o'clock in the evening, at Greenwich, there was an mersion of the first satellite of Jupiter; where was it isible? Jupiter's right ascension at that time was 23 h. 1 m., and longitude about 11 signs 25° 11′, and his decliation 3° 41′ south.

4. On the 31st of December, 1845, at 28 m. 55 sec. past ve o'clock in the evening, at Greenwich, there was an mersion of the first satellite of Jupiter; where was it viible? Jupiter's right ascension at that time was 1 h. 57 m., nd longitude 0 sign 29° 8′, and his declination 10° 40′ outh.

PROBLEM LVIII.

o place the terrestrial globe in the SUNSHINE, *so that it may represent the* NATURAL POSITION *of the earth.*

RULE. If you have a meridian line† drawn upon a horiontal plane, set the north and south points of the wooden orizon of the globe directly over this line; or, place the lobe directly north and south by the mariner's compass, taking care to allow for the variation; bring the place in which you are situated to the brass meridian, and elevate the pole to its latitude; then the globe will correspond in every respect with the situation of the earth itself. The poles, meridians, parallel circles, tropics, and all the circles on the globe, will correspond with the same imaginary circles in the heavens; and each point, kingdom, and state, will be turned towards the real one, which it represents.

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* This is on the supposition that Jupiter moves in the ecliptic, and as e deviates but little therefrom, the solution by this method will be suffiiently accurate. To know if an eclipse of any one of the satellites of upiter will be visible at any place, we are directed by the Nautical lmanac to "find whether Jupiter be 8° above the horizon of the place, ad the sun as much below it."

† As a meridian line is useful for fixing a horizontal dial, and for lacing a globe directly north and south, &c., the different methods of rawing a line of this kind will precede the problems on dialling.

While the sun shines on the globe, one hemisphere will be enlightened, and the other will be in the shade: thus, at one view, may be seen all places on the earth which have day, and those which have night.*

If a needle be placed perpendicularly in the middle of the enlightened hemisphere, (which must of course be upon the parallel of the sun's declination for the given day,) it will cast no shadow, which shows that the sun is vertical at that point; and if a line be drawn through this point from pole to pole, it will be the meridian of the place where the sun is vertical, and every place upon this line will have noon at that time; all places to the west of this line will have morning, and all places to the east of it afternoon. Those inhabitants who are situated on the circle which is the boundary between light and shade, to the westward of the meridian where the sun is vertical, will see the sun rising; those in the same circle to the eastward of this meridian will see the sun setting. Those inhabitants towards the north of the circle, which is the boundary between light and shade, will perceive the sun to the southward of them, in the horizon; and those who are in the same circle towards the south, will see the sun in a similar manner to the north of them.

If the sun shine beyond the north pole at the given time, his declination is as many degrees north as he shines over the pole; and all places at that distance from the pole will have constant day, till the sun's declination decreases, and those at the same distance from the south pole will have constant night.

If the sun do not shine so far as the north pole at the given time, his declination is as many degrees south as the enlightened part is distant from the pole ; and all places within the shade, near the pole, will have constant night, till the sun's declination increases northward. While the globe remains steady in the position it was first placed when the sun is westward of the meridian, you may perceive on the east side of it, in what manner the sun gradually departs from place to place as the night approaches; and when the sun is eastward of the meridian, you may perceive on the western side of it, in what manner the sun advances from place to place as the day approaches.

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* For this part of the problem it would be more convenient if the globe could be properly supported without the frame of it, because the shadow of its stand, and that of its horizon, will darken several parts of the surface of the globe, which would otherwise be enlightened.

PROBLEM LIX.

The latitude of a place being given, to find the hour of the day at any time when the SUN SHINES.

RULE 1. Place the north and south points of the horizon of the globe directly north and south upon a horizontal plane, by a meridian line, or by a mariner's compass, allowing for the variation, and elevate the pole to the latitude of the place; then, if the place be in north latitude, and the sun's declination be north, the sun will shine over the north pole; and if a long pin be fixed perpendicularly in the direction of the axis of the earth, and in the centre of the hour circle, its shadow will fall upon the hour of the day, the figure XII of the hour circle being first set to the brass meridian. If the place be in north latitude, and the sun's declination be above ten degrees south, the sun will not shine upon the hour circle at the north pole.

RULE 2. Place the globe due north and south upon a horizontal plane, as before, and elevate the pole to the latitude of the place; find the sun's place in the ecliptic, bring it to the brass meridian, and set the index of the hour circle to XII; stick a needle perpendicularly in the sun's place in the ecliptic, and turn the globe on its axis till the needle casts no shadow; fix the globe in this position, and the index will show the hour before 12 in the morning, or after 12 in the afternoon.

RULE 3. Divide the equator into 24 equal parts from the point Aries, on which place the number VI; and proceed westward VII, VIII, IX, X, XI, XII, I, II, III, IV, V, VI, which will fall upon the point Libra, VII, VIII, IX, X, XI, XII, I, II, III, IV, V*; elevate the pole to the latitude, place the globe due north and south upon a horizontal plane, by a meridian line, or a good mariner's compass, allowing for the variation, and bring the point Aries to the brass meridian; then observe the circle which is the boundary between light and darkness westward of the brass meridian; and it will intersect the equator in the given hour in the morning; but, if the same circle be eastward of the brass meridian, it will intersect the equator in the given hour in the afternoon.

Or, Having placed the globe upon a true horizontal plane, set it due north and south by a meridian line; elevate the pole to the latitude, and bring the point Aries to the brass meridian, as before; then tie a small string, with a noose, round the elevated pole, stretch its other end beyond the globe, and move it so that the shadow of the string may fall upon the depressed axis; at that instant its shadow upon the equator will give the hour.†

Problem LX.

To find the sun's altitude, by placing the globe in the SUNSHINE.

Rule. Place the globe upon a truly horizontal plane, stick a needle perpendicularly over the north pole‡, in the direction of the axis of the globe, and turn the pole towards the sun, so that the shadow of the needle may fall upon the middle of the brass meridian; then elevate or depress the pole till the needle casts no shadow; for then it will point directly to the sun; the elevation of the pole above the horizon will be the sun's altitude.

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* On *Adams'* globes the antarctic circle is thus divided, by which the problem may be solved.

† The learner must remember that the time shown in this problem is solar time, as shown by a sun-dial; and, therefore, to agree with a good clock or watch, it must be corrected by a table of equation of time. See a table of this kind among the succeeding problems.

‡ It would be an improvement on the globes were our instrument-makers to drill a very small hole in the brass meridian over the north pole.

PROBLEM LXI.

To find the sun's declination, his place in the ecliptic, and his azimuth, by placing the globe in the SUNSHINE.

RULE. Place the globe upon a truly horizontal plane, in a north and south direction by a meridian line, and elevate the pole to the latitude of the place; then, if the sun shine beyond the north pole, his declination is as many degrees north as he shines over the pole; if the sun do not shine so far as the north pole, his declination is as many degrees south as the enlightened part is distant from the pole. The sun's declination being found, his place may be determined by Prob. XX.

Stick a needle in the parallel of the sun's declination for the given day*, and turn the globe on its axis till the needle casts no shadow: fix the globe in this position, and screw the quadrant of altitude over the latitude; bring the graduated edge of the quadrant to coincide with the sun's place, or the point where the needle is fixed, and the degree on the horizon will show the azimuth.

PROBLEM LXII.

To draw a meridian line† *upon a horizontal plane, and to determine the four cardinal points of the horizon.*

RULE. Describe several circles from the centre of the horizontal plane, in which centre fix a straight wire perpendicular to the plane; mark in the morning where the end of the shadow touches one of the circles; in the afternoon mark where the end of the shadow touches the same circle; divide the arc of the circle contained between these two points into two equal parts; a line drawn from the point of division to the centre of the plane will be a true meridian, or north and south line; and if this line be bisected by a perpendicular, that perpendicular will be an east and west line; thus you will have the four cardinal points; but, to be very exact, the plane must be truly horizontal, the wire must be exactly perpendicular to the plane, and the extremity of its shadow must be compared, not only upon one of the circles, as above described, but upon several of them.

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* On *Adams'* globes the torrid zone is divided into degrees by dotted lines, so that the parallel of the sun's declination is instantly found; in using other globes, observe the declination on the brass meridian, and stick a needle perpendicularly in the globe under that degree.

† The method here given of drawing a meridian line, evidently supposes that the sun's declination does not change, during the interval, between the observations. As, however, the sun's declination undergoes a perceptible change in the space of four or six hours at certain times of the year, (about the equinoxes, for instance,) it will be proper, in order to avoid, as much as possible, any inaccuracy from this cause, to make the observations about the time of the summer solstice, at which season of the year the sun changes his declination so slowly as to create no error worth regarding.

PROBLEM LXIII.

To make a horizontal dial for any latitude.

DEFINITIONS AND OBSERVATIONS. — Dialling, or the art of constructing dials, is founded entirely on astronomy; and, as the art of measuring time is of the greatest importance, so the art of dialling was formerly held in the highest esteem, and the study of it was cultivated by all persons who had any pretensions to science. Since the invention of clocks and watches, dialling has not been so much attended to, though it will never be entirely neglected; for, as clocks and watches are liable to stop and go wrong, that unerring instrument, a true sun-dial, is used to correct and to regulate them.

Suppose the globe of the earth to be transparent (as represented by *Fig.* 4. *in Plate* II.), with the hour circles, or meridians, &c. drawn upon it, and that it revolves round a real axis N S, which is opaque and casts a shadow; it is evident that, whenever the edge of the plane of any hour circle or meridian points exactly to the sun, the shadow of the axis will fall upon the opposite hour circle or meridian. Now, if we imagine any opaque plane to pass through the centre of this transparent globe, the shadow of half the axis N E will always fall upon one side or other of this intersecting plane.

Let A B C D represent the plane of the horizon of London, B N the elevation of the pole or latitude of the place; so long as the sun is above the horizon, the shadow of the upper half N E of the axis will fall somewhere upon the upper side of the plane A B C D. When the edge of the plane of any hour circle, as F, G, H, I, K, L, M, O, points directly to the sun, the shadow of the axis, which axis is coincident with *this plane*, marks the respective hour line upon the plane of the horizon ABCD: the hour line upon the horizontal plane is, therefore, a line drawn from the centre of it, to that point where this plane intersects the meridian opposite to that on which the sun shines. Thus, when the sun is upon F, the meridian of London, the shadow of NE the axis will fall upon E, XII. By the same method the rest of the hour lines are found by drawing for every hour a line from the centre of the horizontal plane to that meridian, which is diametrically opposite to the meridian pointing exactly to the sun. If, when the hour circles are thus found, all the lines be taken away except the semi-axis NE, what remains will be a horizontal dial for the given place. From what has been premised, the following observations naturally arise: —

1. The gnomon of every sun-dial must always be parallel to the axis of the earth, and must point directly to the two poles of the world.

2. As the whole earth is but a point when compared with the heavens, therefore, if a small sphere of glass be placed on any part of the earth's surface, so that its axis be parallel to the axis of the earth, and the sphere have such lines upon it, and such a plane within it as above described; it will show the hour of the day as truly as if it were placed at the centre of the earth, and the body of the earth were as transparent as glass.

3. In every horizontal dial the angle which the style, or gnomon, makes with the horizontal plane, must always be equal to the latitude of the place for which the dial is made.

RULE FOR PERFORMING THE PROBLEM. — Elevate the pole so many degrees above the horizon as are equal to the latitude of the place; bring the point Aries to the brass meridian; then, as globes in general* have meridians drawn through every 15 degrees of longitude, eastward and westward from the point Aries, observe where these meridians intersect the horizon, and note the number of degrees between each of them; the arcs between the respective hours will be equal to these degrees. The dial must be numbered XII at the brass meridian, thence XI, X, IX, VIII, VII, VI, V, IV, &c. towards the west, for morning hours; and, I, II, III, IV, V, VI, VII, VIII, &c. for evening hours. No more hour lines need be drawn than what will answer to the sun's continuance above the horizon on the longest day at the given place. The style or gnomon of the dial must be fixed in the centre of the dial-plate, and make an angle therewith equal to the latitude of the place. The face of the dial may be of any shape, as round, elliptical, square, oblong, &c. &c.

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* On *Cary's* large globes the meridians are drawn through every *ten* degrees, an alteration which answers no useful purpose whatever, and is in many cases very inconvenient. To solve this problem, by these globes, meridians must be drawn through every *fifteen* degrees with a pencil.

EXAMPLE. To make an horizontal dial for the latitude of London.

Having elevated the pole 51½ deg. above the horizon, and brought the point Aries to the brass meridian, you will find the meridians on the eastern part of the horizon, reckoning from 12, to be 11° 50′, 24° 20′, 38° 3′, 53° 35′, 71° 6′, and 90°, for the hours I, II, III, IV, V, and VI; or, if you count from the east towards the south, they will be 0°, 18° 54′, 36° 25′, 51° 57′, 65° 40′, and 78° 10′, for the hours VI, V, IV, III, II, I, reckoning from VI o'clock backward to XII. There is no occasion to give the distances farther than VI, because the distances from XII to VI in the forenoon are exactly the same as from XII to VI in the afternoon; and hour lines continued through the centre of the dial are the hours on the opposite parts thereof.

The following table, calculated by spherical trigonometry, contains not only the hour arcs, but the halves and quarters from XII to VI: —

Hours.	Hour Angles.	Hour Arcs.	Hours.	Hour Angles.	Hour Arcs.
XII	0° 0′	0° 0′	3¼	48° 45′	41° 45′
12¼	3 45	2 56	3½	52 30	45 34
12½	7 30	5 52	3¾	56 15	49 30
12¾	11 15	8 51	IV	60 0	53 35
I	15 0	11 50	4¼	63 45	57 47
1¼	18 45	14 52	4½	67 30	62 6
1½	22 30	17 57	4¾	71 15	66 33
1¾	26 15	21 6	V	75 0	71 6
II	30 0	24 20	5¼	78 45	75 45
2¼	33 45	27 36	5½	82 30	80 25
2½	37 30	31 0	5¾	86 15	85 13
2¾	41 15	34 28	VI	90 0	90 0
III	45 0	38 3			

The calculation of the hour arcs by spherical trigonometry is extremely easy; for while the globe remains in the position above described, it will be seen that a right angled spherical triangle is formed, the perpendicular of which is the latitude, its base the hour arc, and its vertical angle the hour angle. Hence,

Radius, sine of 90°
Is to sine of the latitude;
As tangent of the hour angle,
Is to the tangent of the hour arc on the horizon.

It may be observed here, that if a horizontal dial, which shows the hour by the top of the perpendicular gnomon, be made for a place in the torrid zone, whenever the sun's declination exceeds the latitude of the place, the shadow of the gnomon will *go back* twice in the day, once in the forenoon and once in the afternoon; and the greater the difference between the latitude and the sun's declination is, the farther the shadow will go back. In the 38th chapter of Isaiah, *Hezekiah* is promised that his life shall be prolonged 15 years, and as a sign of this, he is also promised that the shadow of the sun-dial of *Ahaz* shall go back ten degrees. This was truly, as it was then considered, a *miracle;* for, as *Jerusalem*, the place where the dial of *Ahaz* was erected, was out of the torrid zone, the shadow could not possibly go back from any natural cause.

PROBLEM LXIV.

To make a vertical dial facing the south, in north latitude.

DEFINITIONS AND OBSERVATIONS. — The horizontal dial, as described in the preceding problem, was supposed to be placed upon a pedestal, and as the sun always shines upon such a dial when he is above the horizon, provided no objects intervene, it is the most complete of all kinds of dials. The next in utility is the vertical dial, facing the south in north latitudes; that is, a dial standing against the wall of a building which exactly faces the south.

Supposing the globe to be transparent, as in the foregoing problem (*see Figure* 5. *Plate* II.), with the hour circles or meridians F, G, H, I, K, L, M, O, &c. drawn upon it; ADCB an opaque vertical plane perpendicular to the horizon, and passing through the centre of the globe. While the globe revolves round its axis NS, it is evident that, if the semi-axis ES be opaque and cast a shadow, this shadow will always fall upon the plane ABC, and mark out the hours as in the preceding problem. By comparing *Fig.* 5. with *Fig.* 4. in *Plate* II., it will appear that the plane surface of every dial whatever is parallel to the horizon of some place or other upon the earth, and that the elevation of the style or gnomon above the dial's surface, when it faces the south, is always equal to the latitude of the place whose horizon is parallel to that surface. Thus it appears that SP, which is the co-latitude of London, is the latitude of the place whose horizon is represented by the plane ADCB: for, let the south pole of the globe be elevated 38½ degrees above the southern point of the horizon, and the point Aries be brought to the brass meridian; then, if the globe be placed upon a table, so as to rest on the south point of the wooden horizon, it will have exactly the appearance of *Fig.* 5. *Plate* II.; the wooden horizon will represent the opaque plane ADCB, the south point will be at B, and the north point at D under London, the east point at C, and the west point at A. Hence we have the following

Rule for performing the problem: — If the place be in north latitude, elevate the south pole to the complement of that latitude; bring the point Aries to the brass meridian; then supposing meridians to be drawn through every 15° of longitude, eastward and westward from the point Aries (as is generally the case), observe where these meridians intersect the horizon, and note the number of degrees between each of them; the arcs between the respective hours will be equal to these degrees. The dial must be numbered XII, at the brass meridian, thence XI, X, IX, VIII, VII, VI, towards the west, for morning hours; and I, II, III, IV, V, VI, towards the east, for evening hours. As the sun cannot shine longer upon such a dial as this than from VI in the morning to VI in the evening, the hour lines need not be extended any farther.

Example. To make a vertical dial for the latitude of London.

Elevate the south pole 38½ degrees above the horizon, and bring the point Aries to the brass meridian; then the meridians will intersect the horizon, reckoning from the south towards the east, in the following degrees: — 9° 28′, 19° 45′, 31° 54′, 47° 9′, 66° 42′, and 90°, for the hours I, II, III, IV, V, VI: or, if you count from the east towards the south, they will be 0°, 23° 18′, 42° 51′, 58° 6′, 70° 15′, 80° 32′, for the hours VI, V, IV, III, II, I. The distances from XII to VI in the forenoon are exactly the same as the distances from XII to VI in the afternoon.

The following table contains not only the hour arcs, but the halves and quarters from XII to VI; it is calculated exactly in the same manner as the table in the preceding problem, using the complement of the latitude instead of the latitude: —

Hours.	Hour Angles.	Hour Arcs.	Hours.	Hour Angles.	Hour Arcs.
XII	0° 0′	0° 0′	3¼	48° 45	35° 22′
12¼	3 45	2 20	3½	52 30	39 3
12½	7 30	4 41	3¾	56 15	42 58
12¾	11 15	7 3	IV	60 0	47 9
I	15 0	9 28	4¼	63 45	51 36
1¼	18 45	11 56	4½	67 30	56 20
1½	22 30	14 27	4¾	71 15	61 23
1¾	26 15	17 4	V	75 0	66 43
II	30 0	19 45	5¼	78 45	72 17
2¼	33 45	22 35	5½	82 30	78 3
2½	37 30	25 32	5¾	86 15	84 0
2¾	41 15	28 38	VI	90 0	90 0
III	45 0	31 54			

The student will recollect that the time shown by a sun-dial is not the exact time of the day, as shown by a watch or clock (see Definitions *55*, *56*, and *57*., page 12.). A good clock measures time equally, but a sun-dial (though used for regulating clocks and watches) measures time unequally. The following table will show to the nearest minute how much a clock should be faster or slower than a sun-dial; such a table should be put upon every horizontal sun-dial: —

Days and Months.	Minutes.		Days and Months.	Minutes.		Days and Months.	Minutes.		Days and Months.	Minutes.	
Jan. 1	4		April 1	4	Clock faster.	Aug. 9	5	Clock faster.	Oct. 27	16	Clock slower than the Dial.
3	5		4	3		15	4		Nov. 15	15	
5	6		7	2		20	3		20	14	
7	7		11	1		24	2		24	13	
9	8		15	0		28	1		27	12	
12	9		*			31	0		30	11	
15	10	Clock faster than the Dial.	19	1	Clock slower.	*			Dec. 2	10	
18	11		24	2		Sept. 3	1	Clock slower than the Dial.	5	9	
21	12		30	3		6	2		7	8	
25	13		May 13	4		9	3		9	7	
31	14		29	3		12	4		11	6	
Feb. 10	15		June 5	2		15	5		13	5	
21	14		10	1		18	6		16	4	
27	13		15	0		21	7		18	3	
Mar. 4	12		*			24	8		20	2	
8	11		20	1	Clock faster.	27	9		22	1	
12	10		25	2		30	10		24	0	
15	9		29	3		Oct. 3	11		*		
19	8		July 5	4		6	12		26	1	Cl. faster.
22	7		11	5		10	13		28	2	
25	6		28	6		14	14		30	3	
28	5					19	15				

Dials may be constructed on all kinds of planes, whether horizontal or inclined; a vertical dial may be made to face the south, or any point of the compass; but the two dials already described are the most useful. To acquire a complete knowledge of dialling, the gnomonical projection of the sphere, and the principles of spherical trigonometry, must be thoroughly understood; these preliminary branches may be learned from *Emerson*'s Gnomonical Projection, and *Keith*'s Trigonometry. The writers on dialling are very numerous: the last and best treatise on the subject is *Emerson*'s.

CHAPTER II.

Problems performed by the Celestial Globe.

PROBLEM LXV.

To find the right ascension and declination of the sun, or a star.*

RULE. Bring the sun's place, or the given star, to the brass meridian; the degree over it is the declination, and the number of degrees on the equinoctial, between the brass meridian and the point Aries, is the right ascension.

OR, Place both the poles of the globe in the horizon, bring the sun's place or star to the eastern part of the horizon; then the number of degrees which the sun's place or star is northward or southward of the east will be the declination north or south; and the degrees on the equinoctial, from Aries to the horizon, will be the right ascension.

EXAMPLES. 1. Required the right ascension and declination of *α Dubhe* in the back of the Great Bear.

Answer. Right ascension 10h. 54m. or 163° 15′, declination 62° 36′ N.

2. Required the right ascensions and declinations of the following stars.

γ, *Algenib*, in Pegasus.
α, *Schedar*, in Cassiopea.
β, *Mirach*, in Andromeda.
α, *Achernar*, in Eridanus.
α, *Menkar*, in Cetus.
β, *Algol*, in Perseus.
α, *Aldebaran*, in Taurus.
α, *Capella*, in Auriga.
β, *Rigel*, in Orion.
γ, *Bellatrix*, in Orion.
α, *Betelgeux*, in Orion.
α, *Canopus*, in Argo Navis.
α, *Procyon*, in the Little Dog.
α, *Spica*, in Virgo.
α, *Arcturus*, in Boötes.
α, *Vega*, in Lyra.

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* The right ascensions and declinations of the moon and the planets must be found from an ephemeris; because, by their continual change of situation, they cannot be placed on the celestial globe, as the stars are placed.

BLE of the Principal fixed Stars mentioned in the fol-
ing Problems, showing their Magnitude, Right Ascen-
, Declination, and Names, Alphabetically arranged.

	Mag.	Right Ascension.		Declination.	
ne, α in Cancer	4	8h.	0m	12°	30′ N.
ne, the brightest of the seven stars	3	3	37	23	35 N.
aran, the Bull's eye	1	4	26	16	10 N.
min, in Cepheus's shoulder	3	21	15	61	52 N.
ib, in Perseus's side	2	3	12	49	15 N.
ib, in Pegasus's side	2	0	4	14	15 N.
in Medusa's head	2	2	57	40	18 N.
, ε in the Great Bear's tail	2	12	46	57	52 N.
ch, γ in Andromeda's foot	2	1	54	41	31 N.
rd, in Hydra's heart	2	9	19	7	56 S.
ratz, in Andromeda's head	2	0	0	28	10 N.
abah, the Pole Star	2	1	4	88	30 N.
es, the Heart of Scorpio	1	16	19	26	3 S.
rus, in Boötes	1	14	8	20	3 N.
s, the Ram's following horn	2	1	58	22	40 N.
, in the Eagle	1	19	43	8	26 N.
rix, in Orion's left shoulder	2	5	16	6	11 N.
asch, η in the Great Bear's tail	2	13	40	50	8 N.
eux, in Orion's right shoulder	1	5	46	7	22 N.
us, in the Ship Argo	1	6	20	52	36 S.
a, in Auriga's shoulder	1	5	4	45	49 N.
, the Northern Twin	2	7	24	32	14 N.
aroli, Charles's Heart	3	12	48	39	13 N.
, in the Swan's tail	2	20	36	44	41 N.
ola, in the Lion's tail	2	11	40	15	30 N.
, the Northern Pointer	2	10	53	62	39 N.
, γ in the Dragon's head	2	17	54	51	31 N.
haut, the Fish's mouth	1	22	48	30	30 S.
a, α in the Crown	2	15	28	27	17 N.
b, β in the Little Bear's shoulder	2	14	51	74	50 N.
b, α in Pegasus's wing	2	22	56	14	19 N.
ar, in the Whale's jaw	2	2	54	3	26 N.
ζ, in the Great Bear's tail	2	13	17	55	18 N.
, the South Twin	2	7	35	28	26 N.
on, in the Little Dog	1	7	31	5	39 N.
lgethi, in Hercules's head	3	17	7	14	35 N.
lhague, in Ophiucus's head	2	17	28	12	41 N.
ban, in the Dragon's head	2	17	53	51	31 N.
us, in the Lion's heart	1	10	0	12	47 N.
in Orion's foot	1	5	7	8	24 S.
t, in the leg of Pegasus	2	22	56	27	11 N.
ar, in Cassiopeia	3	0	31	55	37 N.
, in the Great Dog	1	6	38	16	29 S.
in the Harp	1	18	26	38	38 N.
el Genubi, α in the South Scale	2	14	42	15	20 S.
el Chamali, β in the North ditto	2	15	8	8	46. S.

PROBLEM LXVI.

To find the latitude and longitude of a star.[*]

RULE. Place the upper end of the quadrant of altitude on the north or south pole of the ecliptic, according as the star is on the north or south side of the ecliptic, and move the other end till the graduated edge of the quadrant comes over the star, and the degree of the quadrant over the star is the latitude; and the number of degrees on the ecliptic, reckoned eastward from the point Aries to the quadrant, is the longitude.

OR, Elevate the north or south pole 66½° above the horizon, according as the given star is on the north or south side of the ecliptic; bring the pole of the ecliptic to that part of the brass meridian which is numbered from the equinoctial towards the pole; then the ecliptic will coincide with the horizon; screw the quadrant of altitude upon the brass meridian over the pole of the ecliptic; keep the globe from revolving on its axis, and move the quadrant till its graduated edge comes over the given star: the degree on the quadrant cut by the star is its latitude; and the sign and degree on the ecliptic cut by the quadrant show its longitude.

EXAMPLES. 1. Required the latitude and longitude of α *Aldebaran* in Taurus.

Answer. Latitude 5° 28′ S., longitude 2 signs 6° 53′; or 6° 53′ in Gemini.

2. Required the latitudes and longitudes of the following stars.

α, *Markab*, in Pegasus.
β, *Scheat*, in Pegasus.
α, *Fomalhaut*, in the S. Fish.
α, *Deneb*, in Cygnus.
α, *Altair*, in the Eagle.
β, *Albireo*, in Cygnus.

α, *Vega*, in Lyra.
γ, *Rastaban*, in Draco.
α, *Antares*, in the Scorpion.
α, *Arcturus*, in Boötes.
β, *Pollux*, in Gemini.
β, *Rigel*, in Orion.

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[*] The latitudes and longitudes of the planets must be found from an ephemeris.

PROBLEM LXVII.

The right ascension and declination of a star, the moon, a planet, or of a comet, being given, to find its place on the globe.

RULE. Bring the given time or degree of right ascension to the brass meridian; then under the given declination on the brass meridian you will find the star or place of the planet.

EXAMPLES. 1. What star has 17 h. 26 m. or 261° 30′ of right ascension, and 52° 25′ north declination?

Answer. β in Draco.

2. On the 15th June, 1845, the moon's right ascension at 6 o'clock in the morning was 13 h. 12 m., and her declination 10° 51′ S.; find her place on the globe at that time.

Answer. She will be near to the star α Spica in Virgo.

What stars have the following right ascensions and declinations? The right ascension is given both in time and measure.

	Right Ascensions. h. m.		Declinations.		Right Ascensions. h. m.		Declinations.
3.	0 31	or 7° 45′	55° 36′ N.	9.	5 38	or 83° 30′	34° 10′ S.
4.	0 46	11 11	59 48 N.	10.	5 47	86 13	44 55 N.
5.	1 45	25 54	19 58 N.	11.	6 37	99 33	16 29 S.
6.	3 8	46 32	9 27 S.	12.	7 24	111 7	32 15 N.
7.	3 35	53 54	23 29 N.	13.	7 35	113 54	28 25 N.
8.	5 6	76 34	8 24 S.	14.	8 38	129 32	7 2 N.

15. On the 3rd of December, 1843, the moon's right ascension at midnight was 2 hrs. 18 min., and her declination 17° 47′ N.; find her place on the globe.

16. On the 1st of May, 1844, the declination of Venus was 26° 22′ N., and her right ascension 5 hrs. 42 min.; find her place on the globe at that time.

17. On the 19th of July, 1845, the declination of Jupiter was 13° N., and his right ascension 2 hrs. 24 min.; find his place on the globe at that time.

PROBLEM LXVIII.

The latitude and longitude of the moon, a star, or a planet, given, to find its place on the globe.

RULE. Place the division of the quadrant of altitude marked O, on the given longitude in the ecliptic, and the upper end on the pole of the ecliptic; then under the given latitude, on the graduated edge of the quadrant, you will find the star, or place of the moon or planet.

EXAMPLES. 1. What star has 0 sign 6° 16′ of longitude, and 12° 36′ N. latitude?

Answer. γ in Pegasus.

2. On the 5th of June, 1845, at midnight, the moon's longitude was about 85° 23′ or 25° 23′ in ♊, and her latitude 2° 37′ S.; find her place on the globe.

What stars have the following latitudes and longitudes?

	Latitudes.	Longitudes.		Latitudes.	Longitudes.
3.	12° 35′ S.	1^s 11° 25′	8.	39° 33′ S.	3^s 11° 13′
4.	5 29 S.	2 6 53	9.	10 4 N.	3 17 21
5.	31 8 S.	2 13 56	10.	0 27 N.	4 26 57
6.	22 52 N.	2 18 57	11.	44 20 N.	7 9 22
7.	16 3 S.	2 25 51	12.	21 6 S.	11 0 56

On the 1st of June, 1845, the longitudes and latitudes of the planets were nearly as follow: required their places on the globe.

	Longitudes.	Latitudes.		Longitudes.	Latitudes.
13.	☿ 1^s 18°	3½° S.	16.	♃ 1^s 0°	1½° S.
14.	♀ 2 15	0½ N.	17.	♄ 10 19½	1 S.
15.	♂ 10 19¼	3¼ S.	18.	♅ 0 10	¼ S.

PROBLEM LXIX.

The day and hour, and the latitude of a place being given, to find what stars are rising, setting, culminating, &c.

RULE. Elevate the pole to the latitude of the place, find the sun's place in the ecliptic, bring it to the brass meridian, and set the index to 12; and then turn the globe till the index point to the given hour; then all the stars on the eastern semi-circle of the horizon will be rising, those on the western semi-circle will be setting, those under the brass meridian above the horizon will be culminating, those above the horizon will be visible at the given time and place, those below will be invisible.

If the globe be turned on its axis from east to west, those stars which do not go below the horizon never set at the given place; and those which do not come above the horizon never rise; or, if the given latitude be subtracted from 90°, and circles be described on the globe parallel to the equinoctial, at a distance from it equal to the degrees in the remainder, they will be the circles of perpetual apparition and occultation.

EXAMPLES. 1. On the 9th of February, when it is nine o'clock in the evening at London, what stars are rising, what stars are setting, and what stars are on the meridian?

Answer. Alphecca, in the northern Crown, is rising; Arcturus and Mirach, in Boötes, just above the horizon; Sirius on the meridian; Procyon and Castor and Pollux a little east of the meridian. The constellations Orion, Taurus, and Auriga, a little west of the meridian; Markab, in Pegasus, just below the western edge of the horizon, &c.

2. On the 20th of January, at two o'clock in the morning at London, what stars are rising, what stars are setting, and what stars are on the meridian?

Answer. Vega in Lyra, the head of the Serpent, Spica Virginis, &c. are rising; the head of the Great Bear, the claws of Cancer, &c. on the meridian; the head of Andromeda, the neck of Cetus, and the body of Columba Noachi, &c. are setting.

3. At ten o'clock in the evening at Edinburgh, on the 15th of November, what stars are rising, what stars are setting, and what stars are on the meridian?

4. What stars do not set in the latitude of London, and at what distance from the equinoctial is the circle of perpetual apparition?

5. What stars do not rise to the inhabitants of Edinburgh, and at what distance from the equinoctial is the circle of perpetual occultation?

6. What stars never rise at Otaheite, and what stars never set at Jamaica?

7. How far must a person travel southward from London to lose sight of the Great Bear?

8. What stars are continually above the horizon at the north pole, and what stars are constantly below the horizon thereof?

What stars are rising, setting, and culminating at the following places, at the respective times?

9. London, May 1, 11 P.M.
10. Glasgow, January 20, 6 P.M.
11. Naples, August 8, 5 A.M.
12. Hull, July 30, 10 P.M.
13. Mexico, November 14, 7 P.M.
14. Cape of Good Hope, January 1, 8 P.M.

PROBLEM LXX.

The latitude of a place, day of the month, and hour being given, to place the globe in such a manner as to represent the heavens at that time; in order to find out the relative situations and names of the constellations and remarkable stars.

RULE. Take the globe out into the open air, on a clear starlight night, where the surrounding horizon is uninterrupted by different objects; elevate the pole to the latitude of the place, and set the globe due north and south by a meridian line, or by a mariner's compass, taking care to make a proper allowance for the variation; find the sun's place in the ecliptic, bring it to the brass meridian, and set the index of the hour-circle to 12; then turn the globe on its axis till the index point to the given hour; fix the globe in this position, then the flat end of a pencil being placed on any star on the globe so as to point towards the centre, the other end will point to that particular star in the heavens.

PROBLEM LXXI.

To find when any star, or planet, will rise, come to the meridian, and set at any given place.

RULE. Elevate the pole equal to the latitude of the place; find the sun's place in the ecliptic, bring it to the brass meridian, and set the index of the hour-circle to 12. Then turn the globe till the star* or planet comes to the eastern part of the horizon, the index will show the time when it rises; and by continuing the motion of the globe westward till the star, &c., comes to the meridian, and to the western part of the horizon successively, the index will show the time of culminating and setting.

EXAMPLES. 1. At what time will Arcturus rise, come to the meridian, and set, at London, on the 7th of September?

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* The latitude and longitude (or the right ascension and declination of the planet) must be taken from an ephemeris, and its place on the globe must be determined by Prob. LXVIII. (or LXVII.)

Answer. It will rise at a quarter past seven o'clock in the morning, come to the meridian at a quarter past three in the afternoon, and set at a quarter before eleven o'clock at night.

2. On the 16th of September, 1843, the right ascension of Jupiter was 21 hrs. 27 min., and his declination 16° 15′ S.; at what time did he rise, culminate, and set, at Greenwich, and whether was he a morning or an evening star?

Answer. Jupiter rose at five o'clock in the afternoon, came to the meridian at about quarter before ten in the evening, and set at half-past two in the morning. Here Jupiter was an evening star, because he both rose and set after the sun.

3. At what time does Sirius rise, set, and come to the meridian of London on the 31st of January?

4. On the 22nd of November, 1845, the right ascension of Venus was 19 hrs. 7 min., and her declination 25° 15′ S.; at what time did she rise, culminate, and set at London, and whether was she a morning or an evening star?

5. At what time does Aldebaran rise, come to the meridian, and set at Dublin, on the 25th of November?

6. On the 10th of November, 1845, the right ascension of Mars was 22 hrs. 35 min., and his declination 10° 49′ S.; at what time did he rise, set, and come to the meridian of Greenwich?

At what time will the following stars rise, set, and come to the meridian on the respective days?

7. Vega, May 20, at Paris.
8. Rigel, August 8, at Botany Bay.
9. Arietis, November 30, at Bath.
10. Castor, February 20, at Norwich.
11. Regulus, April 10, at Rome.
12. Markab, August 8, at Exeter.
13. Algol, September 7, at Yarmouth.
14. Procyon, October 11, at Jerusalem.

PROBLEM LXXII.

To find the amplitude of any star, its oblique ascension and descension, and its diurnal arc for any given day.

RULE. Elevate the pole to the latitude of the place, and bring the given star to the eastern part of the horizon; then the number of degrees between the star and the eastern point of the horizon will be its rising amplitude; and the degree of the equinoctial cut by the horizon will be the oblique ascension: set the index of the hour-circle to 12, and turn the globe westward till the given star comes to the western edge of the horizon: the hours passed over by the index will be the star's diurnal arc, or continuance above the horizon. The setting amplitude will be the number of degrees between the star and the western point of the horizon, and the oblique descension will be represented by that degree of the equinoctial which is intersected by the horizon, reckoning from the point Aries.

EXAMPLES. 1. Required the rising and setting amplitude of Sirius, its oblique ascension, oblique descension, and diurnal arc, at London?

Answer. The rising amplitude is 27° to the south of the east; setting amplitude 27° south of the west; oblique ascension 120°; oblique descension 77°; and diurnal arc 9 hours 6 minutes.

2. Required the rising and setting amplitude of Aldebaran, its oblique ascension, oblique descension, and diurnal arc at London?

3. Required the rising and setting amplitude of Arcturus, its oblique ascension, oblique descension, and diurnal arc at London?

4. Required the rising and setting amplitude of γ Bellatrix, its oblique ascension, oblique descension, and diurnal arc, at London?

Required the amplitude, oblique ascension, and descension, and time of continuance above the horizon, of the following stars at the respective places?

5. Pollux, at Bristol.
6. Gemma, at Damascus.
7. Antares, at Glasgow.
8. Vega, at Algiers.
9. Betelgeux, at Edinburgh.
10. Menkar, at Quito.
11. β in Taurus, at Paris.
12. Capella, at London.

PROBLEM LXXIII.

The latitude of a place given, to find the time of the year at which any known star rises or sets ACRONICALLY, *that is, when it rises or sets at sun-setting.*

RULE. Elevate the pole to the latitude of the place, bring the given star to the eastern edge of the horizon, and observe what degree of the ecliptic is intersected by the western edge of the horizon, the day of the month answering to that degree will show the time when the star rises at sun-set. Turn the globe westward on its axis till the star comes to the western edge of the horizon, and observe what degree of the ecliptic is intersected by the horizon as before; the day of the month answering to that degree will show the time when the star sets with the sun.

EXAMPLES.—1. At what time does Arcturus rise acronically at Ascra* in Bœotia, the birth-place of Hesiod; the latitude of Ascra, according to Ptolemy, being 37° 45′ N.?

Answer. When Arcturus is at the eastern part of the horizon, the eleventh degree of Aries will be at the western part answering to the 1st of April†, the time when Arcturus rises acronically; and it will set acronically on the 30th of November.

2. At what time of the year does Aldebaran rise acronically at Athens, in 38° N. latitude; and at what time of the year does it set acronically?

3. On what day of the year does γ in the extremity of the wing of Pegasus rise acronically at London; and on what day of the year does it set acronically?

4. On what day of the year does ϵ in the right foot of Lepus rise acronically at London; and on what day of the year does it set acronically?

On what days do the following stars rise and set acronically, at the respective places?

5. β in Auriga, at Jamaica.
6. β in Cetus, at Cadiz.
7. Algenib, at Florence.
8. Arietes, at Glasgow.
9. The Pleiades, at Moscow.
10. Vega, at Cairo.

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* See page 16.

† Hence Arcturus now rises acronically in latitude 37° 45′ N. about 100 days after the winter solstice. Hesiod, in his *Opera & Dies*, lib. ii. verse 185. says:—

When from the solstice sixty wintry days
Their turns have finished, mark, with glittering rays,
From Ocean's sacred flood *Arcturus* rise,
Then first to gild the dusky evening skies.

Here is a difference of 40 days in the acronical rising of this star (supposing Hesiod to be correct), between the time of Hesiod and the present time; and as a day answers to about 59′ of the ecliptic (see the note page 15.), 40 days will answer to 39°; consequently, the winter solstice in the time of Hesiod was in the 9th deg. of Aquarius. Now, the recession of the equinoxes is about $50\frac{1}{4}''$ in a year; hence $50\frac{1}{4}''$: 1 year :: 39° : 2794 years since the time of Hesiod; so that he lived 952 years before Christ, by this mode of reckoning. Lempriere, in his Classical Dictionary, says Hesiod lived 907 years before Christ.

PROBLEM LXXIV.

The latitude of a place given, to find the time of the year at which any known star rises or sets COSMICALLY, *that is, when it rises or sets at sun-rising.*

RULE. Elevate the pole to the latitude of the place, bring the given star to the eastern edge of the horizon, and observe what sign and degree of the ecliptic are intersected by the horizon; the month and day of the month, answering to that sign and degree, will show the time when the star rises with the sun. Turn the globe westward on its axis till the star comes to the western edge of the horizon, and observe what sign and degree of the ecliptic are intersected by the eastern edge, as before; these will point out on the horizon the time when the star sets at sun-rising.

EXAMPLES. 1. At what time of the year do the Pleiades set cosmically at Miletus in Ionia, the birth-place of Thales; and at what time of the year do they rise cosmically; the latitude of Miletus, according to Ptolemy, being 37° N.?

Answer. The Pleiades rise with the sun on the 11th of May, and they set at the time of sun-rising on the 23rd of November.*

2. At what time of the year does Sirius rise with the sun at London; and at what time of the year will Sirius set when the sun rises?

3. At what time of the year does Menkar, in the jaw of

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* Pliny says (Nat. Hist. lib. xviii. cap. 25.), that Thales determined the cosmical setting of the Pleiades to be 25 days after the autumnal equinox. Supposing this observation to be made at Miletus, there will be a difference of 35 days in the cosmical setting of this star since the time of Thales; and, as a day answers to about 59′ of the ecliptic, these days will make about 34° 25′; consequently, in the time of Thales, the autumnal equinoctial colure passed through 4° 25″ of Scorpio; and, as before, $50\frac{1}{4}''$: 1 year : : 34° 25′ : 2465 years since the time of Thales, so that Thales lived (2465 – 1844) 621 years before the birth of Christ. According to Sir I. Newton's Chronology, Thales flourished 596 years before Christ. Thales was well skilled in geometry, astronomy, and philosophy; he measured the height and extent of the Pyramids of Egypt, was the first who calculated with accuracy a solar eclipse; he discovered the solstices and equinoxes, divided the heavens into five zones, and recommended the division of the year into 365 days. Miletus was situated in Asia Minor, south of Ephesus, and south east of the island of Samos.

Cetus, rise with the sun, and at what time does it set at sun-rising at London?

4. At what time of the year does Procyon, in the Little Dog, set when the sun rises at London, and at what time of the year does it rise with the sun?

At what time of the year do the following stars rise with the sun and set at sun-rising at the respective places?

5. Atair, in Aquila, at London.
6. *a* Ras Algethi, in Hercules, at Rome.
7. Capella, in Auriga, at Tunis.
8. Algenib, in Perseus, at Bayonne.
9. Deneb, in Cygnus, at Washington.
10. Antares, in Scorpio, at Moscow.

PROBLEM LXXV.

To find the time of the year when any given star rises or sets HELIACALLY.[*]

RULE. The heliacal rising and setting of the stars will vary according to their different degrees of magnitude and brilliancy; for it is evident that the brighter a star is when above the horizon, the less the sun will be depressed below the horizon when that star first becomes visible. According to Ptolemy, stars of the *first* magnitude are seen rising and setting when the sun is 12° below the horizon; stars of the *second* magnitude require the sun's depression to be 13°; stars of the *third* magnitude 14°, and so on, reckoning 1° for each magnitude. This being premised:

TO SOLVE THE PROBLEM. Elevate the pole so many degrees above the horizon as are equal to the latitude of the place, and screw the quadrant of altitude on the brass meridian over that latitude; bring the given star to the eastern edge of the horizon, and move the quadrant of altitude till it intercepts the ecliptic 12° below the horizon, if the star be of the first magnitude; 13°, if the star be of the second magnitude; 14°, if it be of the third magnitude, &c.: the point of the ecliptic, cut by the quadrant, will show the day of the month, on the horizon, when the star rises heliacally. Bring the given star to the western edge of the horizon, and move the quadrant of altitude till it intersects the ecliptic below the western edge of the horizon, in a similar manner as before; the point of the ecliptic cut by the quadrant will show the day of the month, on the horizon, when the star sets heliacally.

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[*] See Definition 90. p. 23.

EXAMPLES. 1. At what time does β Tauri, or the bright star in the Bull's Horn, of the second magnitude, rise and set heliacally at Rome?

Answer. The quadrant will intercept the 3rd of Cancer 13° below the eastern horizon, answering to the 24th June; and the 7th of Gemini 13° below the western horizon, answering to the 28th of May.

2. At what time of the year does Sirius, or the Dog Star, rise heliacally at Alexandria in Egypt; and at what time does it set heliacally at the same place?

Answer. The latitude of Alexandria is 31° 13′ north; the quadrant will intersect the 12th of Leo, 12° below the eastern horizon, answering to the 4th of August*; and the 2nd of Gemini, 12° below the western horizon, answering to the 23rd of May.

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* The ancients reckoned the beginning of the *Dog Days* from the heliacal rising of Sirius, and their continuance to be about 40 days. Hesiod informs us that the hottest season of the year (*Dog Days*) ended about 50 days after the summer solstice. We have determined in the note of Example 1. Prob. LXXIII. (though perhaps not very accurately), that the winter solstice, in the time of Hesiod, was in the 9th degree of Aquarius; consequently, the summer solstice was in the 9th degree of Leo: now, it appears from above, that Sirius rises heliacally at Alexandria when the sun is in the 12th degree of Leo; and, as a degree nearly answers to a day, Sirius rose heliacally in the time of Hesiod about four days after the summer solstice; and if the Dog Days continued 40 days, they ended about 44 days after the summer solstice. The Dog Days in our almanacks begin on the 3rd of July, which is 12 days after the summer solstice, and end on the 11th of August, which is 51 days after the summer solstice, and their continuance is 39 days. Hence it is plain that the Dog Days of the moderns have no reference whatever to the rising of Sirius, for this star rises heliacally at London on the 25th of August and, as well as the rest of the stars, varies in its rising and setting according to the variation of the latitudes of places, and therefore it could have no influence whatever on the temperature of the atmosphere; yet, as the Dog Star rose heliacally at the commencement of the hottest season in Egypt, Greece, &c. in the earlier ages of the world, it was very natural for the ancients to imagine that the heat, &c. was the effect of this star. A few years ago, the Dog Days in our almanacks began at the *Cosmical* rising of Procyon, viz. on the 30th of July, and continued to the 7th of September; but they are now, very properly, altered, and made not to depend on the variable rising of any particular star, but on the summer solstice.

3. At what time of the year does Arcturus rise heliacally at Jerusalem, and at what time does it set heliacally?

4. At what time of the year does Cor Hydræ rise and set heliacally at London?

5. At what time of the year does Procyon rise and set heliacally at London?

6. If the precession of the equinoxes be 50¼ seconds in a year, how many years will elapse, from 1845, before Sirius, the Dog Star, will rise heliacally at Christmas, at Cairo in Egypt?* When this period happens, Sirius will perhaps no longer be accused of bringing sultry weather.

PROBLEM LXXVI.

The latitude of a place and day of the month being given, to find all those stars that rise and set ACRONICALLY, COSMICALLY, *and* HELIACALLY.†

RULE. Elevate the pole so many degrees above the horizon as are equal to the latitude of the given place. Then,

1. *For the acronical rising and setting*, find the sun's place in the ecliptic, and bring it to the *western* edge of the horizon, and all the stars along the eastern edge of the horizon will rise acronically, while those along the western edge will set acronically.

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* This question is of too delicate a nature to admit of a correct solution by a globe: the answer given to it in the key is, therefore, merely an approximation to the truth.

† This problem is the reverse of the three preceding problems. Their principal use is to illustrate several passages in the ancient writers, such as Hesiod, Virgil, Columella, Ovid, Pliny, &c. (See definition 64., page 14.) The knowledge of these poetical risings and settings of the stars was held in great esteem among the ancients, and was very useful to them in adjusting the times set apart for their religious and civil duties, and for marking the seasons proper for the several parts of husbandry; for the knowledge which the ancients had of the motions of the heavenly bodies was not sufficient to adjust the true length of the year; and, as the returns of the seasons depend upon the approach of the sun to the tropical and equinoctial points, so they made use of these risings and settings to determine the commencement of the different seasons, the time of the overflowing of the Nile, &c. The knowledge which the moderns have acquired of the motions of the heavenly bodies renders such observations as the ancients attended to in a great measure useless, and, instead of watching the rising and setting of particular stars for any remarkable season, they can sit by the fire-side and consult an almanac.

2. *For the cosmical rising and setting*, bring the sun's place to the *eastern* edge of the horizon, and all the stars along that edge of the horizon will rise cosmically, while those along the western edge will set cosmically.

3. *For the heliacal rising and setting*, screw the quadrant of altitude over the latitude, turn the globe eastward on its axis till the sun's place cuts the quadrant 12° below the horizon; then all stars of the first magnitude, along the eastern edge of the horizon, will will rise heliacally; and, by continuing the motion of the globe eastward till the sun's place intersects the quadrant in 13, 14, 15, &c. degrees below the horizon, you will find all the stars of the *second, third, fourth*, &c. magnitudes, which rise heliacally on that day. By turning the globe westward on its axis, in a similar manner, and bringing the quadrant to the western edge of the horizon, you will find all the stars that set heliacally.

EXAMPLES. 1. What stars rise and set cosmically at Edinburgh, on the 11th of June?

Answer. The bright star Castor, Aldebaran in Taurus, Fomalhaut in the southern Fish, &c. rise cosmically; those stars in the body of Leo Minor, the arm of Virgo, the right foot of Boötes, part of the Centaur, &c. set cosmically.

2. What stars rise and set acronically at Drontheim in Norway, latitude 63° 26′ N. on the 18th of May?

Answer. Altair in the Eagle, the head of the Dolphin, &c. rise acronically; and Aldebaran in Taurus, Betelgeux in Orion, &c. set acronically.

3. What star of the first magnitude rises heliacally at London, on the 7th of October?

4. What star of the first magnitude sets heliacally at London, on the 5th of May?

5. What stars rise and set acronically at London, on the 26th of September?

6. What stars rise and set cosmically at London, on the 23d of March?

What stars will rise and set acronically at Edinburgh, on the following days?

7. December 15. 9. July 4. 11. May 11.
8. August 8. 10. January 20. 12. February 12.

What stars will rise and set cosmically on the following days at York?

13. December 1. 15. August 8. 17. February 4.
14. November 20. 16. January 11. 18. March 9.

What stars of the first and second magnitude will rise heliacally at London, on:—

19. August 2.
20. July 12.
21. January 1.
22. October 13.
23. August 12.
24. September 4.

PROBLEM LXXVII.

To illustrate the precession of the equinoxes.

OBSERVATIONS. All the stars in the different constellations continually increase in longitude; consequently either the whole starry heavens have a slow motion from west to east, or the equinoctial points have a slow motion from east to west. In the time of Meton*, the first star in the constellation Aries, now marked β, passed through the vernal equinox, whereas it is now upwards of 30°† to the eastward of it.

ILLUSTRATION. Elevate the north pole 90° above the horizon, then will the equinoctial coincide with the horizon; bring the pole‡ of the ecliptic to that part of the brass meridian which is numbered from the north pole towards the equinoctial, and make a mark upon the brass meridian above it; let this mark be considered as the pole of the world, let the equinoctial represent the ecliptic, and let the ecliptic be considered as the equinoctial; then count $38\frac{1}{2}$°, the complement of the latitude of London, from this pole upwards, and mark where the reckoning ends, which will be at 75°, on the brass meridian, from the southern point of the horizon; this mark will stand over the latitude of London.

Now turn the globe gently on its axis from east to west, and the equinoctial points will move the same way, while, at the same time, the pole of the world* will describe a circle round the pole of the ecliptic† of 46° 56′ in diameter; this circle will be completed in a Platonic year‡, consisting of 25,868 years, at the rate of 50·1 seconds in a year, and the pole of the heavens will vary its situation a small matter every year. When 12,934½ years, being half the Platonic year, are completed, (which may be known by turning the globe half round, or till the point Aries coincides with the eastern point of the horizon,) that point of the heavens which is now 8½° south of the zenith of London will be the north pole§, as may be seen by referring to the mark which was made over 75° on the meridian.

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* Meton was a famous mathematician of Athens, who flourished about 1430 years before Christ. In a book called *Enneadecaterides* or cycle of 19 years, he endeavoured to adjust the course of the sun and of the moon: and attempted to show that the solar and lunar years would regularly begin from the same point in the heavens.

† If the precession of the equinoxes be $50''\cdot 1$ in a year, and if the equinoctial colure passed through β Arietis 430 years before Christ, the longitude of this star ought in 1844 to be 31° 38′ 47″; for 1 year : $50''\cdot 1$ :: 2274 years (= 430 + 1844) : 31° 38′ 47″, and this longitude is not far from the truth.

‡ The pole of the ecliptic is that point on the globe, in the arctic circle, where the circular lines meet.

PROBLEM LXXVIII.

To find the distances of the stars from each other in degrees.

RULE. Lay the quadrant of altitude over any two stars, so that the division marked o may be on one of the stars; the degrees between them will show their distance, or the angle which these stars subtend, as seen by a spectator on the earth.

EXAMPLES. 1. What is the distance between Vega in Lyra, and Altair in the Eagle?

Answer. 34 degrees.

2. Required the distance between β in the Bull's Horn, and γ Bellatrix in Orion's shoulder?

3. What is the distance between β Pollux in Gemini, and α in Canis Minor?

4. What is the distance between η, the brightest of the Pleiades, and β in Canis Major?

5. What is the distance between ε in Orion's girdle, and ζ in Cetus?

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* Let it be remembered that the pole of the ecliptic on the globe here represents the pole of the world.

† Take notice, that the extremity of the globe's axis here represents the pole of the ecliptic.

‡ A Platonic year is a period of time determined by the revolution of the equinoxes; this period being once completed, the ancients were of opinion that the world was to begin anew, and the same series of things to return over again. See the 64th Definition, page 14.

§ See page 196.

6. What is the distance between Arcturus in Boötes, and Regulus in Leo?

What is the number of degrees between the following stars:—

7. α in Ursa Major, and α the Pole Star.
8. Arcturus in Boötes, and Gemma in the Crown.
9. Menkar in Cetus, and β in Andromeda.
10. Castor in Gemini, and Procyon in Canis Minor.

PROBLEM LXXIX.

To find what stars lie in or near the moon's path, or what stars the moon can eclipse, or make a near approach to.

RULE. Find the moon's longitude and latitude, or her right ascension and declination, in an ephemeris, for several days, and mark the moon's places on the globe (as directed in Problems LXVIII. or LXVII.); then, by laying a thread, or the quadrant of altitude, over these places, you will see nearly the moon's path*, and, consequently, what stars lie in her way.

EXAMPLES. 1. What stars were in or near the moon's path, on the 28th, 29th, 30th, and 31st of March, 1844?

	☽'s Longitude at Midnight.				Latitude.
28th,	112° 43′	or	♋ 22° 43′	- -	3° 10′ S.
29th,	125 37	-	♌ 5 37	- -	3 50 S.
30th,	138 58	-	♌ 18 58	- -	4 30 S.
31st,	152 49	-	♍ 2 49	- -	4 55 S.

Answer. The stars will be found to be ε and δ Geminorum, θ, and δ Cancri, π Leonis, &c.

2. On the 7th, 8th, 9th, 10th, and 11th of December, 1845, what stars lay near the moon's path, her right as-

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* The situation of the moon's orbit for any particular day may be found thus: find the place of the moon's ascending node in the Ephemeris, mark that place and its antipodes (being the descending node) on the globe: half the way between these points make marks 5° 20′ on the north and south side of the ecliptic, viz. let the northern mark be between the ascending and descending node, and the southern between the descending and ascending node; a thread tied round these four points will show the position of the moon's orbit.

cension* and declination at midnight of the days annexed being as under?

7th,	☽'s right ascension	0^h	29^m	declination	6° 34′ N.
8th,	- -	1	19	- -	10 40 N.
9th,	- -	2	10	- -	14 11 N.
10th,	- -	3	1	- -	16 59 N.
11th,	- -	3	52	- -	18 58 N.

PROBLEM LXXX.

Given the latitude of the place and the day of the month, to find what planets will be above the horizon after sun-setting.

RULE. Elevate the pole so many degrees above the horizon as are equal to the latitude of the place; find the sun's place in the ecliptic, and bring it to the western part of the horizon, or to ten or twelve degrees below; then look in the Ephemeris for that day and month, and you will find what planets are above the horizon; such planets will be fit for observation on that night.

EXAMPLES. 1. What planets were visible after the sun had descended ten degrees† below the horizon of London, on the 12th of November, 1844? Their right ascensions and declinations being as follow:—

	Right Ascension.	Declination.		Right Ascension.	Declination.	
☿	15^h 3^m	17° 11′ S.	♃	23^h 41^m	3° 42′ S.	at Noon.
♀	12 32	1 34 S.	♄	20 17	20 22 S.	
♂	13 0	5 18 S.	♅	0 11	0 24 N.	

Answer. Jupiter, Saturn, and Herschel.

2. What planets were above the horizon of London when the sun had descended ten degrees below, on the 25th of

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* In this example the right ascension is given (in time) to the nearest minute, and the declination to the nearest minute of a degree. This mode of expressing the right ascension, viz. in time, is agreeable to the form of the Nautical Almanack.

† The planets are not visible till the sun is a certain number of degrees below the horizon, and these degrees are variable according to the brightness of the planets. Mercury becomes visible when the sun is about 10 deg. below the horizon; Venus when the sun's depression is 5 degrees; Mars 11° 30′; Jupiter 8°; Saturn 10°; and the Georgian 17° 30′.

December, 1845? Their right ascensions and declinations being as follow:—

Right Ascension.		Declination.	Right Ascension.		Declination.
☿	18^{h} 38′	21°20′ S.	♃	1^{h} 57′	10° 37′ N.
♀	21 35	15 56 S.	♄	21 16	17 4 S.
♂	0 8	0 40 N.	♅	0 25	1 54 N.

PROBLEM LXXXI.

Given the latitude of the place, day of the month, and hour of the night or morning, to find what planets will be visible at that hour.

RULE. Elevate the pole so many degrees above the horizon as are equal to the latitude of the place: find the sun's place in the ecliptic, bring it to the brass meridian, and set the index of the hour-circle to 12; then turn the globe till the index points to the given hour; let the globe rest in this position, and look in the Nautical Almanac for the right ascension and declination of the planets*; then, if any of them be in the signs which are above the horizon, such planets will be visible.

EXAMPLES. 1. On the 1st of September, 1844, the right ascension and declination of the planets, by the Nautical Almanac, were as follow: were any of them visible at London at five o'clock in the morning?

Right Ascension.		Declination.	Right Ascension.		Declination.	
☿	12^{h} 19^{m}	4° 30′ S.	♃	0^{h} 8^{m}	0° 51′S.	at noon.
♀	7 56	15 38 N.	♄	20 16	20 25 S.	
♂	10 10	12 34 N.	♅	0 21	1 24 N.	

Answer. Jupiter, Venus, and Mars.

2. On the 1st of November, 1845, the right ascensions and declinations of the planets, as given in the Nautical Almanac, were as follow: were any of them visible at London at seven o'clock in the evening?

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* As the longitude and latitude are not given in the Nautical Almanac, the editor of the present edition has frequently introduced the right ascension and declination, instead of, as formerly, the longitude and latitude.

	Right Ascension.	Declination.		Right Ascension.	Declination.	
☿	14h 40m	15° 43′ S.	♃	2h 14m	11° 56′ N.	at noon.
♀	17 20	25 24 S.	♄	21 1	18 7 S.	
♂	22 20	12 49 S.	♅	0 27	2 9 N.	

PROBLEM LXXXII.

The latitude of the place and day of the month being given, to find how long Venus rises before the sun when she is a morning star, and how long she sets after the sun when she is an evening star.

RULE. Elevate the pole so many degrees above the horizon as are equal to the latitude of the place; find the right ascension and declination of Venus in the Nautical Almanac, and mark her place on the globe; find the sun's place in the ecliptic, and bring it to the brass meridian; then, if the place of Venus be to the right hand of the meridian, she is an evening star; if to the left hand, she is a morning star.

When Venus is an evening star. Bring the sun's place to the western edge of the horizon, and set the index of the hour-circle to 12; turn the globe westward on its axis till Venus coincides with the western edge of the horizon; and the hours passed over by the index will show how long Venus sets after the sun.

When Venus is a morning star. Bring the sun's place to the eastern edge of the horizon, and set the index of the hour circle to 12; turn the globe eastward on its axis till Venus comes to the eastern edge of the horizon, and the hours passed over by the index will show how long Venus rises before the sun.

NOTE. *The same rule will serve for Jupiter, by marking his place instead of that of Venus.*

EXAMPLES. 1. On the 1st of May, 1844, the right ascension of Venus was 5 hours 42 min., or 2 signs 26°, or 26° in Gemini, declination 26° 22′ N.; was she a morning or an evening star? If a morning star, how long did she rise before the sun at London? If an evening star, how long was she above the horizon after the sun had set?

Answer. Venus was an evening star, and set about four hours after the sun.

2. On the 1st of December, 1845, the right ascension of Venus was 19 hours 51 min., and her declination 23° 38′ S; was she a morning or an evening star? If a morning star, how long did she rise before the sun at London? If an evening star, how long was she above the horizon after the sun had set.

3. On the 1st of January, 1846, the right ascension of Jupiter was 1 hour 57 minutes, and his declination 10° 40′ N.; was he a morning or an evening star? If a morning star, how long did he rise before the sun at London? If an evening star, how long was he above the horizon after the sun had set?

PROBLEM LXXXIII.

The latitude of a place and day of the month being given, to find the meridian altitude of any star or planet.*

RULE. Elevate the pole so many degrees above the horizon as are equal to the latitude of the given place; then,

For a star. Bring the given star to the brass meridian; the degrees on the meridian contained between the star and the horizon will be the altitude required.

For the moon or a planet. Look in an ephemeris for the planet's right ascension and declination for the given month and day, and mark its place on the globe (as in Prob. LXVII.); bring the planet's place to the brass meridian; and the number of degrees between that place and the horizon will be the altitude.

EXAMPLES. 1. What is the meridian altitude of Aldebaran in Taurus, at London? *Ans.* 54½°.

2. What is the meridian altitude of Arcturus in Boötes at London?

3. On the 5th of March, 1845, the right ascension of Jupiter † was 22 hrs. 53 min., and declination 8 degrees 11 minutes south; what was his meridian altitude at London?

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* The meridian altitudes of the stars on the globe, in the same latitude, are invariable: therefore when the meridian altitude of a star is sought, the day of the month need not be attended to.

† The places of the planets may be taken out of the ephemeris for noon *without sensible error*, because their declinations vary less than that of *the moon.*

4. On the 6th of November, 1845, the right ascension of Saturn was 21 deg. 2 min., and declination 18 deg. 5 min. south; what was his meridian altitude at London?

5. On the 18th of April, 1845, at the time of the moon's passage over the meridian of Greenwich, her right ascension was 10 hours 56 min., and declination 1° 29′ N.; required her meridian altitude at Greenwich?*

6. Required the moon's meridian altitude on the 1st of January, 1846: the right ascension being 22 hours 4 min., and declination 6° 38′ south?

Note. This problem may be performed without a globe having the latitude of the place, and the star or planet's declination, as Problem XLI. For by taking the declination in the last example from the co-latitude† of London, we have 38° 30′—6° 38′=31° 52′

PROBLEM LXXXIV.

To find all those places on the earth to which the moon will be nearly vertical on any given day.

RULE. Look in an ephemeris, or the Nautical Almanac, for the moon's latitude and longitude for the given day, and mark her place on the globe (as in Prob. LXVIII.); bring this place to the brass meridian, and observe the degree above it; for all places on the earth having that latitude will have the moon vertical (or nearly so) when she comes to their respective meridians.

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* By the Nautical Almanac, page IV. of the month, the moon will transit the meridian at 9 hrs. 8 min., or neglecting the minutes, 9 hrs. Then, turning to page IX. of the same month, we find her right ascension at that time to be 10 hrs. 56 min., and her declination 1° 29′ or 1½° nearly, from which the meridional altitude may be obtained as near the truth as the operation by a globe will admit; or, without the globe, the declination 1½° + 38½° (the co-lat. of London) = 40°, the ☽'s meridian altitude.

The moon will have the greatest and least meridian altitude to all the inhabitants north of the equator, when her ascending node is in Aries; for her orbit making an angle of 5⅓° with the ecliptic, her greatest altitude will be 5⅓° more than the greatest meridional altitude of the sun, and her least meridional altitude 5⅓° less than that of the sun. The greatest altitude of the sun at London is 62°; the moon's greatest altitude is therefore 67° 20′. The least meridional altitude of the sun at London is 15°; the least meridional altitude of the moon is therefore 9° 40′.

† The co-latitude (*complement of latitude*) of any place is what it wants of being 90 degrees. For example, the lat. of London is 51° 30′; therefore the co-lat. = 90° − 51° 30′ = 38° 30′, or 38½°.

OR: Take the moon's declination from page V.*, &c. of the Nautical Almanac, and mark whether it be north or south; then, by the terrestrial globe, or by a map, find all places having the same latitude as the moon's declination, and those will be the places to which the moon will be successively vertical on the given day. If the moon's declination be north, the places will be in north latitude, and *vice versâ.*

EXAMPLES. 1. On the 8th of October, 1845, the moon's longitude at midnight was 9 signs 22 deg. 25 min., and her latitude 4 deg. 44 min. north; over what places did she pass nearly vertical?

Answer. She was nearly vertical to all places that have 16° 54′ south lat. Hence, she was nearly vertical to the southern parts of New Holland; the south of Madagascar, Angora, and Cape Negro, in Africa; and Porto Seguro, South America.

2. On the 9th of December, 1845, the moon's declination at midnight was $14\frac{1}{4}$° N. nearly; over what places on the earth will she pass nearly vertically?

3. What is the greatest north declination which the moon can possibly have, and to what places will she be then vertical?

PROBLEM LXXXV.

Given the latitude of a place, day of the month, and the altitude of a star, to find the hour of the night, and the star's azimuth.

RULE. Elevate the pole equal to the latitude of the place, and screw the quadrant of altitude upon the brass meridian over that latitude: find the sun's place in the ecliptic, bring it to the brass meridian, and set the index of the hour-circle to 12; bring the lower end of the quadrant of altitude to that side of the meridian on which the star was situated when observed; then move the globe and the quadrant, till the star cut the quadrant at the given altitude, the foot of the quadrant will be opposite the azimuth, and the index will show the hour.

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* The right ascension and declination of the moon for every hour commence with *page V. and end at page XII.* of each month in the Nautical *Almanac.*

EXAMPLES. 1. At London, on the 28th of December, the star Deneb in the Lion's tail, marked β, was observed to be 40 deg. above the horizon, and east of the meridian; what hour was it, and what was the star's azimuth?

Answer. By bringing the sun's place to the meridian, and turning the globe westward on its axis till the star cuts 40 deg. of the quadrant *east of the meridian*, the index will have passed over 14¼ hours; consequently, the star has 40 deg. of altitude east of the meridian, 14 hours from noon, or at a quarter past two o'clock in the morning. Its azimuth will be 60¼ deg. from the south towards the east.

2. At London, on the 28th of December, the star β, in the Lion's tail, was observed to be westward of the meridian, and to have 40 deg. of altitude: what hour was it, and what was the star's azimuth?

Answer. 8' A. M. azimuth, 62° S. W.

3. At London, on the 1st of September, the altitude of Benetnasch in Ursa Major, marked η, was observed to be 36 degrees above the horizon, and west of the meridian: what hour was it, and what was the star's azimuth?

4. On the 21st of December, the altitude of Sirius, when west of the meridian at London, was observed to be 8 deg. above the horizon; what hour was it, and what was the star's azimuth?

5. On the 12th of August, Menkar in the Whale's jaw, marked α, was observed to be 37 deg. above the horizon of London, and eastward of the meridian; what hour was it, and what was the star's azimuth?

6. At London, 6th of February, Rigel, in Orion's foot, was observed to have 16° altitude in the S.E.; required the hour and azimuth?

7. At the Cape of Good Hope, on the 2d of May, Spica, in Virgo, was observed to have 50° altitude when west of the meridian; what was the azimuth and the hour?

8. At Glasgow, 23d September, the altitude of Benetnasch, in the tail of Ursa Major, was observed to be 45°, when to the east of the meridian; required the azimuth and the hour?

9. The altitude of Procyon, in Canis Minor, was observed

to be 20°, when west of the meridian, on February 20th, at Paris; required the azimuth and the hour?

10. If the altitude of Arietes, in Aries on September 1st, be 38° when to the east of the meridian, what is the azimuth and the hour?

11. The altitude of Arcturus was 38° to the east of the meridian April 1st, at Vienna; what was the hour and the azimuth?

PROBLEM LXXXVI.

Given the latitude of a place, day of the month, and hour of the day, to find the altitude of any star, and its azimuth.

RULE. Elevate the pole equal to the latitude of the place, and screw the quadrant of altitude upon the brass meridian over that latitude; find the sun's place in the ecliptic, bring it to the brass meridian, and set the index of the hour-circle to 12; then turn the globe till the index point to the given hour. Bring the quadrant of altitude over the star, then the azimuth will be found on the horizon opposite the foot of the quadrant, and the degree of the quadrant cut by the star will be its altitude.

EXAMPLES. 1. What are the altitude and azimuth of Capella at Rome, when it is five o'clock in the morning on the 2d of December?

Answer. The altitude is 41 deg. 58 min., and the azimuth 60 deg. 50 min. from the north towards the west.

2. Required the altitude and azimuth of Altair, in Aquila, on the 6th of October, at nine o'clock in the evening at London?

3. On what point of the compass does the star Aldebaran bear at the Cape of Good Hope, on the 5th of March, at a quarter past eight o'clock in the evening; and what is its altitude?

Required the altitude and azimuth of Alcyone in the Pleiades marked η, on the 21st of December, at four o'clock in the morning, at London?

5. What are the altitude and azimuth of Antares at London, July 1st at 9 P.M.?

6. What are the altitude and azimuth of Alpheratz, in Andromeda, at Bergen, on Nov. 30th at 11 P.M.

7. What are the altitude and azimuth of Algol, in the head of Medusa, at Rome, Dec. 10th, at 8 P.M.?

8. What are the altitude and azimuth of Deneb, in Cygnus, at Naples, on May 1st at 5 A.M.

9. What are the altitude and azimuth of Spica, in Virgo, at Dover, on March 1st, at midnight?

What are the altitude and azimuth of the following stars at London at 8 P.M. on 6th February?

10. Bellatrix.
11. Sirius.
12. Aldebaran.
13. Castor.
14. Pollux.
15. Procyon.
16. Menkar.
17. Regulus.
18. Mirach.

PROBLEM LXXXVII.

Given the latitude of the place, day of the month, and azimuth of a star, to find the hour of the night and the star's altitude.

RULE. Elevate the pole equal to the latitude of the place, and screw the quadrant of altitude upon the brass meridian over that latitude; find the sun's place in the ecliptic, bring it to the brass meridian, and set the index of the hour-circle to 12; bring the lower end of the quadrant of altitude to coincide with the given azimuth on the horizon, and hold it in that position; turn the globe till the given star comes to the graduated edge of the quadrant, and the index will show the hour and the degrees on the quadrant, reckoning from the horizon to the star, will be the altitude.

EXAMPLES. 1. At London, on the 28th of December, the azimuth of Deneb in the Lion's tail marked β, was 62½ deg. from the south towards the west; what hour was it, and what was the star's altitude?

Answer. Eight o'clock in the morning; and the star's altitude will be 40 deg.

2. At London, on the 5th of May, the azimuth of Cor Leonis, or Regulus, marked α, was 74 deg. from the south towards the west; required the star's altitude, and the hour of the night?

3. On the 8th of October, the azimuth of the star marked β, in the shoulder of Auriga, was 50 deg. from the north towards the east; required its altitude at London, and the hour of the night?

4. On the 10th of September, the azimuth of the star

marked ε, in the Dolphin, was 20 deg. from the south towards the east; required its altitude at London, and the hour of the night?

What are the altitude and the hour at London, November 1st, when the following stars have the annexed azimuth?

5. Capella, 47° N.E.
6. Scheat, in Pegasus, 55° S.W.
7. Fomalhaut, 15° S.W.
8. Arietes, 18° S.E.
9. Rigel, 41° S.E.
10. Alioth, 27° N.W.

What are the altitude and hour at Edinburgh on May 20th, when the following stars have the annexed azimuth?

11. Arcturus, 81° N.W.
12. Vega, 38° N.E.
13. Pollux, 47° S.E.
14. Atair, 77° S.E.
15. Capella, 25° N.W.
16. Benetnasch, 22° N.W.

PROBLEM LXXXVIII.

Two stars being given, the one on the meridian, and the other on the east or west part of the horizon, to find the latitude of the place.

RULE. Bring the star which was observed to be on the meridian, to the brass meridian; keep the globe from turning on its axis, and elevate or depress the pole till the other star comes to the eastern or western part of the horizon; then the elevation of the pole will be the latitude.

EXAMPLES. 1. When the two pointers of the Great Bear, marked α and β, or Dubhe and β, were on the meridian, I observed Vega in Lyra to be rising; required the latitude?

Answer. 27 deg. north.

2. When Arcturus in Boötes was on the meridian, Altair in the Eagle was rising; required the latitude?

3. When the star marked β in Gemini was on the meridian, ε in the shoulder of Andromeda was setting; required the latitude?

4. In what latitude are α and β, or Sirius and β in Canis Major rising, when Algenib, or α, in Perseus, is on the meridian?

What are the latitudes when the first mentioned of the following stars is on the meridian, and the second rising or setting?

5. Capella, Cor Hydra, rising.
6. Arcturus, Atair, rising.
7. Antares, Regulus, setting.
8. Vega, Fomalhaut, rising.
9. Atair, Algol, rising.
10. Gemma, Castor, setting.

PROBLEM LXXXIX.

The latitude of the place, the day of the month, and two stars that have the same azimuth, being given, to find the hour of the night.

RULE. Elevate the pole equal to the latitude of the place, and screw the quadrant of altitude upon the brass meridian over that latitude; find the sun's place in the ecliptic, bring it to the brass meridian, and set the index of the hour-circle to 12; turn the globe on its axis till the two given stars coincide with the graduated edge of the quadrant of altitude; the index will show the hour; and the common azimuth of the two stars will be found on the horizon.

EXAMPLES. 1. At what hour, at London, on the 1st of May, will Altair in the Eagle, and Vega in the Harp, have the same azimuth, and what will that azimuth be?

Answer. Three o'clock in the morning; and the azimuth will be 42⅓° from the south towards the east.

2. On the 10th of September, what is the hour at London, when Deneb in Cygnus, and Markab in Pegasus, have the same azimuth, and what is the azimuth?

3. At what hour on the 15th of April will Arcturus and Spica Virginis have the same azimuth at London, and what will that azimuth be?

4. On the 20th of February, what is the hour at Edinburgh when Capella and the Pleiades have the same azimuth, and what is the azimuth?

5. On the 21st of December, what is the hour at Dublin when α or Algenib in Perseus, and β in the Bull's horn, have the same azimuth, and what is the azimuth?

At what hour have the following stars the same azimuth at London on December 21st?

6. Vega and Atair.
7. Mirach and Arietes.
8. Vega and Ras Alhague.
9. Gemma and Spica.
10. Castor and Procyon.
11. α Serpens and Gemma.

PROBLEM XC.

The latitude of the place, the day of the month, and two stars that have the same altitude, being given, to find the hour of the night.

RULE. Elevate the pole so many degrees above the horizon as are equal to the latitude of the place, and screw the quadrant of altitude upon the brass meridian over that latitude; find the sun's place in the ecliptic, bring it to the brass meridian, and set the index to 12; turn the globe on its axis till the two given stars coincide with the given altitude on the graduated edge of the quadrant; the index will show the hour.

EXAMPLES. 1. At what hour at London, on the 2d of September, will Markab in Pegasus, and α in the head of Andromeda, have each 30 deg. of altitude?

Answer. At a quarter past eight in the evening.

2. At what hour at London, on the 5th of January, will α, Menkar, in the Whale's jaw, and α, Aldebaran, in Taurus, have each 35 deg. of altitude?

3. At what hour at Edinburgh, on the 10th of November, will α, Altair, in the body of the Eagle, and ζ in the tail of the Eagle, have each 35 deg. of altitude?

4. At what hour at Dublin, on the 15th of May, will η, Benetnasch, in the Great Bear's tail, and γ, in the shoulder of Boötes, have 56 deg. of altitude?

At what hour at London, on August 8th, will the following stars have the same altitude.

5. Capella and Algol
6. Rigel and Procyon
7. Algenib and Scheat in Pegasus.
8. Capella and Castor.
9. Regulus and Spica.
10. Dubhe and Arcturus.

PROBLEM XCI.

The altitudes of two stars having the same azimuth, and that azimuth being given, to find the latitude of the place.

RULE. Place the graduated edge of the quadrant of altitude over the two stars, so that each star may be exactly under its given altitude on the quadrant; hold the quadrant in this position, and elevate or depress the pole till the division marked 0, on the lower end of the quadrant, coincides with the given azimuth on the horizon: when this is effected, the elevation of the pole will be the latitude.

EXAMPLES. 1. The altitude of Arcturus was observed to be 40°, and that of Cor. Caroli 68°; their common azimuth at the same time was 71° from the south towards the east; required the latitude?

Answer. 51½° north.

2. The altitude of ε in Castor was observed to be 40°, and that of β in Procyon 20°; their common azimuth at the same time was 73½°; from the south towards the east; required the latitude?

3. The altitude of α, Dubhe, was observed to be 40°, and that of γ in the back of the Great Bear 29½°, their common azimuth at the same time was 30° from the north towards the east; required the latitude?

4. The altitude of Vega, or α in Lyra, was observed to be 70°, and that of α in the head of Hercules 39½°, their common azimuth at the same time was 60° from the south towards the west; required the latitude?

5. The altitude of Betelgeuse was 15°, and Capella 55°, when their azimuth was 57° S. E.; required the latitude?

6. The altitude of Aldebaran was 20°, and of Menkar 47°, and their azimuth 59° N. E.; required the latitude?

7. The altitude of Altair was 15°, when the altitude of Vega was 49°, and their azimuth 78° S. E.; required the latitude?

PROBLEM XCII.

The day of the month being given, and the hour when any known star rises or sets, to find the latitude of the place.

RULE. Find the sun's place in the ecliptic, bring it to the brass meridian, and set the index of the hour-circle to 12; then turn the globe till the index point to the given hour, and elevate or depress the pole till the given star coincides with the horizon; then the elevation of the pole will show the latitude.

EXAMPLES. 1. In what latitude does ε, Mirach, in Bootes, rise at half-past twelve o'clock at night, on the 10th of December?

Answer. 51½° north.

2. In what latitude does Cor. Leonis, or Regulus, rise at ten o'clock at night, on the 21st of January?

3. In what latitude does β, Rigel in Orion, set at four o'clock in the morning, on the 21st of December?

4. In what latitude does β, Capricornus, set at eleven o'clock at night, on the 10th of October?

PROBLEM XCIII.

To find on what day of the month any given star passes the meridian at any given hour.

RULE. Bring the given star to the brass meridian, and set the index to the given hour. Turn the globe till the index point to 12 at noon, and the degree of the ecliptic cut by the meridian, found on the horizon, will show the day of the month.

EXAMPLES. 1. On what day of the month does Procyon come to the meridian of London at three o'clock in the morning?

Answer. December 1.

2. On what day of the month, does α, Alderamin, in Cepheus, come to the meridian of Edinburgh at ten o'clock at night?

Answer. September 9.

3. On what day of the month does β, Deneb in the Lion's tail, come to the meridian of Dublin at nine o'clock at night?

4. On what day of the month, does Arcturus in Boötes come to the meridian of London at noon?

5. On what day of the month does δ in the Great Bear, come to the meridian of London at midnight?

6. On what day of the month does Aldebaran come to the meridian of Philadelphia at five o'clock in the morning at London?

On what days of the month does Algol come to the meridian at the following hours.

7. 5 A.M.
8. 9 A.M.
9. Noon.
10. 4 P.M.
11. 8 P.M.
12. Midnight.

On what days of the month does Rigel come to the meridian at the following hours.

13. Noon.
14. 4 P.M.
15. 7 P.M.
16. Midnight.
17. 7 A.M.
18. 9 A.M.

PROBLEM XCIV.

The day of the month being given, to find at what hour any given star comes to the meridian. *

RULE. Find the sun's place in the ecliptic, bring it to the brass meridian, and set the index of the hour-circle to 12; turn the globe on its axis till the given star comes to the brass meridian, and the index will show the hour.

OR, WITHOUT THE GLOBE.

Subtract the right ascension of the sun for the given day from the right ascension of the star, and the remainder will be the time of the star's culminating *nearly*. If the sun's right ascension exceeds the star's, add 24 hours to the star's before you subtract.

EXAMPLES. 1. At what hour does Cor Leonis, or Regulus, come to the meridian of London on the 23rd of September?

Answer. ¾ past 9 A. M.

2. At what hour does Arcturus come to the meridian of London on the 9th of February?

Answer. ½ past 4 A. M.

3. Required the hours at which the following stars come to the meridian of London on the respective days annexed:—

1. Bellatrix, January 9th.
2. Menkar, May 18th.
3. Etanin, Sept. 22nd.
4. α Dubhe, Dec. 20th.
5. β Mirach, October 5th.
6. Aldebaran, Feb. 12th.
7. β Aries, November 5th.
8. β Taurus, January 24th.

9. At what time will Sirius come to the meridian of Greenwich on the 18th of December?

Required at what hour Betelgeux will come to the meridian on the following days?

10. Jan. 1.
11. March 1.
12. May 1.
13. July 1.
14. Sept. 1.
15. Nov. 1.

At what hour do the following stars come to the meridian on the annexed days?

16. Alioth, June 1.
17. Sirius, Feb. 8.
18. Procyon, Jan. 11.
19. Vega, May 9.
20. Arcturus, June 1.
21. Gemma, Oct. 11.

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* This problem is comprehended in Problem LXXI.

PROBLEM XCV.

Given the azimuth of a known star, the latitude, and the hour, to find the star's altitude, and the day of the month.

RULE. Elevate the pole equal to the latitude of the given place, screw the quadrant of altitude upon the brass meridian over that latitude, bring the quadrant to the given azimuth on the horizon, turn the globe till the star coincides with the graduated edge of the quadrant, the degree on which cut by the star will show its altitude; then set the index to the given hour, and turn the globe till the index points to 12 at noon; observe that degree of the ecliptic which is intersected by the graduated edge of the brass meridian, and the day of the month answering thereto, on the horizon, will be the day required.

EXAMPLES. 1. At London, at ten o'clock at night, the aximuth of Spica Virginis was observed to be 40 deg. from the south towards the west; required its altitude, and the day of the month?

Answer. Altitude 20°, June 18.

2. At London, at four o'clock in the morning, the azimuth of Arcturus was 70 deg. from the south towards the west; required its altitude, and the day of the month?

Answer. Altitude 40°, April 12.

3. At Edinburgh, at eleven o'clock at night, the azimuth of *α* Serpentarius, or Ras Alhagus, was 60 deg. from the south towards the east; required its altitude, and the day of the month?

4. At Dublin, at two o'clock in the morning, the azimuth of *β* Pegasi, or Scheat, was 70 deg. from the north towards the east; required its altitude, and the day of the month?

5. At London, at 6 P.M., the azimuth of Vega was 30 N. W.; at 6 P.M. what was the altitude, and the day of the month?

6. At the Cape of Good Hope, at 8 P.M., the azimuth of Canopus was observed to be 30° S. E., required the altitude, and the day of the month?

7. At Glasgow, at 4 A.M., the azimuth of Fomalhaut was observed to be 10° S. E., required the altitude and the day of the month?

PROBLEM XCVI.

The altitudes of two stars being given, to find the latitude of the place.

RULE. Subtract each star's altitude from 90 degrees; take successively the extent of the number of degrees, contained in each of the remainders, from the equinoctial with a pair of compasses; with the compasses thus extended, place one foot successively in the centre of each star, and describe arcs on the globe with a black-lead pencil; these arcs will cross each other in the zenith; bring the point of intersection to that part of the brass meridian which is numbered from the equinoctial towards the poles, and the degree above it will be the latitude.

EXAMPLES. 1. At sea, in north latitude, I observed the altitude of Capella to be 30 deg., and that of Aldebaran 35 deg.; what latitude was I in?

Answer. With an extent of 60° (=90°—30°) taken from the equinoctial, and one foot of the compasses in the centre of Capella, describe an arc towards the north; then with 55° (=90°—35°), taken in a similar manner, and one foot of the compasses in the centre of Aldebaran, describe another arc, crossing the former; the point of intersection brought to the brass meridian will show the latitude to be 20½° north.

2. The altitude of Markab in Pegasus was 30 deg., and that of Altair in the Eagle, at the same time, was 65 deg.; what was the latitude, supposing it to be north?

3. In north latitude, the altitude of Arcturus was observed to be 60 deg., and that of β or Deneb, in the Lion's tail, at the same time, was 70 deg.; what was the latitude?

4. In north latitude, the altitude of Procyon was observed to be 50 deg., and that of Betelgeux in Orion, at the same time, was 58 deg.; required the latitude of the place of observation?

PROBLEM XCVII.

The meridian altitude of a known star being given at any place in north latitude, to find the latitude.

RULE. Bring the given star to the brass meridian, count the number of degrees in the given altitude on the brass meridian from the star towards the south part of the horizon, and mark where the reckoning ends; elevate or depress the pole till this mark coincides with the south point of the horizon, and the elevation of the north pole above the horizon will show the latitude.

EXAMPLES. 1. In what degree of north latitude is the meridian altitude of Aldebaran 52½°?

Answer. 53° 36′ north.

2. In what degree of north latitude is the meridian altitude of β, one of the pointers in Ursa Major, 90°?

3. In what degree of north latitude is γ, in the head of Draco, vertical when it culminates?

4. In what degree of north latitude is the meridian altitude of ϵ or Mirach in Boötes, 68°?

In what degrees of north latitude will the following stars have the annexed meridian altitudes?

5.	Aldebaran	30°	9.	Spica	10°
6.	Rigel	40	10.	Fomalhaut	1
7.	Sirius	7	11.	Denebola	40
8.	Castor	88	12.	Arcturus	70

PROBLEM XCVIII.

The latitude of a place, day of the month, and hour of the day, being given, to find the NONAGESIMAL DEGREE[*] *of the ecliptic, its altitude and azimuth, and the* MEDIUM CŒLI.

RULE. Elevate the north pole to the latitude of the given place, and screw the quadrant of altitude upon the brass meridian over that latitude; find the sun's place in the ecliptic, bring it to the brass meridian, and set the index of the hour-circle to 12; then turn the globe till the index point to the given hour; count 90° upon the ecliptic from the horizon (either eastward or westward), and mark where the reckoning ends, for that point of the ecliptic will be the nonagesimal degree, and the degree of the ecliptic cut by the brass meridian will be the medium cœli; bring the graduated edge of the quadrant of altitude to coincide with the nonagesimal degree of the ecliptic thus found, and the number of degrees on the quadrant, counted from the horizon, will be the altitude of the nonagesimal degree; the azimuth will be seen on the horizon.

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[*] The nonagesimal degree of the ecliptic is that point which is the most elevated above the horizon, and is measured by the angle which the ecliptic makes with the horizon at any elevation of the pole; or, it is the distance beneath the zenith of the place and the pole of the ecliptic. This angle is frequently used in the calculation of solar eclipses. The medium cœli, or mid-heaven, is that point of the ecliptic which is upon the meridian.

Examples. 1. On the 21st of June, at forty-five minutes past three o'clock in the afternoon, at London, required the point of the ecliptic which is the nonagesimal degree, its altitude and azimuth, the longitude of the medium cœli, and its altitude, &c.?

Answer. The nonagesimal degree is 10° in Leo, its altitude is 54°, and its azimuth 22° from the south towards the west, or nearly S.S.W. The mid-heaven, or point of the ecliptic under the brass meridian, is 24° in Leo, and its altitude above the horizon is 52°. The degree of the equinoctial cut by the brass meridian, reckoning from the point Aries, is the right ascension of the mid-heaven, which in this example is 146°. The rising point of the ecliptic will be found to be 10° in Scorpio, and the setting point 10° in Taurus. If the graduated edge of the quadrant be brought to coincide with the sun's place, the sun's altitude will be found to be 39° and his azimuth 78½° from the south towards the west, or nearly W. by S.

2. At London, on the 24th of April, at nine o'clock in the morning; required the point of the ecliptic which is the nonagesimal degree, its altitude and azimuth, the point of the ecliptic which is the mid-heaven, &c.?

3. At Limerick, in 52° 22′ north latitude, on the 15th of October, at five o'clock in the afternoon; required the point of the ecliptic which is the nonagesimal degree, its altitude and azimuth, the point of the ecliptic which is the mid-heaven, &c.?

4. At Dublin, in latitude 53° 21′ north, on the 15th of January, at two o'clock in the afternoon; required the longitude, altitude, and azimuth, of the nonagesimal degree; and the longitude and altitude of the medium cœli, &c.?

Problem XCIX.

The latitude of a place, day of the month, and the hour, together with the altitude and azimuth of a star, being given, to find the star.

Rule. Elevate the pole equal to the latitude of the place, and screw the quadrant of altitude on the brass meridian over that latitude; find the sun's place in the ecliptic, bring it to the brass meridian, and set the index of the hour circle to 12; then turn the globe till the index point to the given hour; next bring the foot of the quadrant to the given azimuth on the horizon; then, immediately under the given altitude on the graduated edge of the quadrant, you will find the star.

EXAMPLES. 1. At London, on the 21st of December, at four o'clock in the morning, the altitude of a star was 50°, and its azimuth was 37° from the south towards the east; required the name of the star?

Answer. Deneb, or β in the Lion's tail.

2. The altitude of a star was 27°, its azimuth 76½° from the south towards the west, at eleven o'clock in the evening, at London, on the 11th of May; what star was it?

3. At London, on the 21st of December, at four o'clock in the morning, the altitude of a star was 8°, and its azimuth 51° from the south towards the west; required the name of the star?

4. At London, on the 1st of September, at nine o'clock in the evening, the altitude of a star was 47°, and its azimuth 73° from the south towards the east; required the name of the star?

PROBLEM C.*

To find very correctly, by the globe, the time of the moon's culminating, or coming to the meridian, on any given day.

RULE. Find the moon's right ascension and declination at noon by the Nautical Almanac, and mark its place on the globe. Also find the sun's place in the ecliptic for the given day; bring it to the meridian, and set the index to 12; turn the globe westward on its axis, till the moon's place comes to the meridian, and observe the hour by the index. Then find in the Nautical Almanac the moon's right ascension and declination at *this time*, and bring that point to the meridian; the time now shown by the index will be very nearly the true time of the moon's passing the meridian.

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* This problem is substituted by the editor for the very incorrect one given in former editions.

OR, WITHOUT THE GLOBE.

Find the moon's age by the table, at page 184, which multiply by ·82*, and cut off two figures from the right hand of the product; the left-hand figures will be the hours; the right-hand figures must be multiplied by 60, for minutes.

EXAMPLES. 1. At what hour, on the 14th of January, 1845, did the moon pass the meridian of Greenwich, the moon's right ascension at noon being 0 hr. 47 min., and declination 9° 15′ N.?

By the Globe. The point of the moon's declination at noon comes to the meridian at about ten minutes past five o'clock in the afternoon; at which time, by page VII. of the month in the Nautical Almanac for 1845, the moon's right ascension will be 0 hr. 57 min.; bringing this last to the meridian, it will be found that the time from noon is 5 hrs. 20 min.) as nearly as can be read off on a globe), and agrees within about one minute of the time of the moon's passage given in page IV. of the month in the Nautical Almanac.

By the Table (*page* 184.). The moon's age is 6, or more nearly 6½, which multiplied by ·82 gives 5·33, that is, 5 hrs. and ·33 over; this multiplied by 60 produces nearly 19 minutes. Hence, by this method, the moon culminates at 5 hrs. 19 min. in the afternoon, nearly as given in the Nautical Almanac, which is 5 hrs. 21·3 min.

2. At what hour, on the 13th of March, 1845, did the moon pass over the meridian at Greenwich, the moon's right ascension at noon being 3 hrs. 29 min., and declination 19° 13′ N.?

3. At what hour, on the 1st of January, 1846, did the moon pass over the meridian at Greenwich, the moon's right ascension at noon being 22 hrs. 4 min., and declination 6° 39′ S.?

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* For, the synodic revolution of the moon being about 29½ days, we have, by the rule of three, as 29½ d. : 24 h :: 1 d. : ·82 h. nearly.

PROBLEM CI.

The day of the month, and time of high water at the full and change of the moon being given, to find the time of high water on the given day at any place within the limits of the table.

RULE. Find the time at which the moon comes to the meridian of the given place by the preceding problem, to which add the time of high water at the given place at the full and change of the moon (taken from the following Table), and the sum will show the Time of high water in the afternoon. If the sum exceed 12 hours, subtract 12 hours and 24 minutes from it, and the remainder will show the time of high water in the morning; but if the sum exceed 24 hours, subtract 24 hours and 48 minutes from it, and the remainder will show the time of high water in the afternoon.

OR, BY THE TABLE, PAGE 234.

Find the moon's age by the Table, at page 234., and take out the time from the right-hand column thereof answering to the moon's age; to which add the time of high water at the full and change of the moon (taken from the following Table), and the sum will show the time of high water in the afternoon. If the sum exceed 12 hours, subtract 12 hours and 24 minutes from it, and the remainder will show the time of high water in the morning; but if the sun exceed 24 hours, subtract 24 hours and 48 minutes from it, and the remainder will show the time of high water in the afternoon.

OR, THUS:

Find the time of the moon's coming to the meridian of Greenwich on the given day, at page IV. of the month in the Nautical Almanac; take out the correction (from the following Table, page 382.) to correspond to this time, and apply it as the Table directs; to the result add the time of high water at the full and change of the moon (taken from the following Table), and the sum will show the time of high water in the afternoon. If the sum exceed 12 or 24 hours, proceed as above.

EXAMPLES. 1. Required the time of high water at London Bridge on the 29th of April, 1844, the moon's right ascension at noon being 11 hrs. 35 min., and her declination 2° 50′ south?

Answer, By the Globe.—The moon comes to the meridian at	9h.	24m.
Time of high water at the full and change at London	2	7
Time of highwater in the afternoon	11	31
By the Table, page 234.—The moon's age is 12, the time answering to which, in Table, p. 234.	10h.	9m.
Time of high water at the full and change	2	7
Time of high water at 16 min. past 12 at night	12	16
By the Nautical Almanac.—The moon comes to the meridian at	9h.	24m.
The time from the right-hand Table following, answering to 9 hrs. 24 min., is	0	23
Sum	9	47
Time of high water at London at the full and change	2	7
Time of high water 54 min. after 11 at night*	11	54

2. Required the time of high water at London, on the 9th of February, 1844, the moon's right ascension at noon being 13 hrs. 35 min., and her declination 14° 20′ south?

3. Required the time of high water at Aberdeen, on the 9th of February, 1844, the moon's right ascension at noon being 13 hrs. 35 min., and her declination 14° 20′ south?

4. Required the time of high water at Liverpool Dock on the 14th of August, 1845? By the Nautical Almanac the moon comes to the meridian of Greenwich at 9 hrs. 29 min.

5. Required the time of high water at Bristol on the 2nd of September, 1845, the moon's right ascension at noon being 11 hrs. 5 min., and her declination 1° 6′ north?

6. Required the time of high water at Dublin on the 1st of January, 1846, the moon's right ascension at noon being 22 hrs. 4 min., and her declination 6° 38′ south?

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* Here are three methods of performing the same problem, and the results all differ from each other: the first is nearest to the time given in the Nautical Almanac for 1844, p. 546.: which is 11 h. 36 min. For ascertaining the time of high water more accurately, see an Elementary Treatise on the Tides by *Sir J. Lubbock*, published in 1839.

A TABLE

Of the Time of High Water at New and Full Moon at the principal Places in the British Islands. *

	H.	M.		H.	M.
Aberdeen	1	11	Fifeness	2	0
Aberystwith	7	30	Flamborough Head	4	30
Aldborough	10	45	North Foreland	11	20
St. Andrew's	2	0	South Foreland	11	20
Arran Island	11	15	Foulness	6	45
Bamborough	3	30	Fowey	5	30
Banff	0	41	Galway Bay	4	30
Beachy Head.	11	50	Fort George	11	40
St. Bee's Head	10	45	Gravesend	1	30
Belfast	10	5	Greenock	11	45
Bembridge Point	10	15	Hartland Point	4	30
Berwick	2	18	Hartlepool	3	45
Boston	7	15	Harwich	11	30
St. Bride's Bay	6	0	Holyhead	10	0
Bridlington	4	30	Hull	6	0
Bridport	6	0	Kinsale	4	30
Brighton	11	38	Leith	2	22
Bristol	7	15	Limerick	4	30
Caithness Point	9	0	Liverpool Dock	11	22
Cantire, Mull.	6	0	London Bridge	2	7
Cape Clear	4	0	Milford	5	45
Cork Harbour	4	30	Newcastle	4	0
Cowes	10	45	Orfordness	10	4
Cromartie	11	45	Plymouth	5	33
Cromer	7	0	Port Patrick	11	0
Cullen	0	0	Portland	6	15
Dartmouth	6	5	Portsmouth Dock	11	40
Dingle Bay	3	30	Ramsgate Harbour	11	20
Dover	11	10	Rochester	0	45
Dublin Bar	11	12	Sandwich	11	30
Dunbar	2	20	Scarborough	4	25
Dunbarton	11	15	Sligo Bay	5	59
Dundee	2	35	Southampton	11	40
Dungarvon	4	30	Stockton	3	30
Dungeness	10	50	Swansea	5	56
Eddystone	5	15	Tynemouth	2	50
Edinburgh	2	20	Torbay	6	5
Exeter	10	30	Weymouth	6	30
Exmouth Bar	6	25	Whitby	3	45
Falmouth	5	15	Whitehaven	11	15
Fern Island	3	30	Yarmouth Road	8	40

Time of the moon's passing the merid.	Correction to be subtracted or added.	
Hours.	H.	M.
	Sub.	
0	0	0
1	0	1
2	0	34
3	0	50
4	1	3
5	1	9
6	1	3
7	1	35
	Add	
8	0	2
9	0	23
10	0	24
11	0	14
12	0	0
	Sub.	
13	0	17
14	0	34
15	0	50
16	1	3
17	1	9
18	1	3
19	0	35
	Add	
20	0	2
21	0	23
22	0	24
23	0	14
24	0	0

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* Corrected from the Nautical Almanac for 1845.

PART IV.

1. *A promiscuous Collection of Examples for Exercise on the Globes. — A Collection of Questions, with References to the Pages where the Answers will be found; designed as an Assistant to the Tutor in the Examination of his Pupils.*

CHAPTER I.

Promiscuous Examples for Exercise on the Globes.

1. What day of the year is of the same length as the 14th of August?

2. How many miles make a degree of longitude in the latitude of Lisbon?

3. At what hour is the sun due east at London on the 5th of May?

4. There is a place in the parallel of 31 deg. of north latitude, which is 31 deg. distant from London; what place is it?

5. If the sun's meridian altitude at London be 30 deg., what day of the month, and what month, is it?

6. On what month and day is the sun's meridian altitude at Paris equal to the latitude of Paris?

7. When γ Draconis is vertical to the inhabitants of London at 10 o'clock at night; what day of the month, and what month, is it?

8. What is the equation of time dependent on the obliquity of the ecliptic on the 14th of July?

9. I observed the pointers in the Great Bear, on the meridian of London, at eleven o'clock at night; in what month, and on what night, did this happen?

10. On what day of the month, and in what month, will the shadow of a cane placed perpendicular to the horizon of London, at 10 o'clock in the morning, be exactly equal in length to the cane?

11. The earth goes round the sun in 365 days 6 hours nearly; how many degrees does it move in one day, at a

medium? Or, what is the daily apparent mean motion of the sun?

12. The moon goes once round her orbit, from the first point of the sign Aries to the same again, in 27 days 7 hours 43 minutes 5 seconds; what is her mean motion in one day?

13. The moon turns round her axis, from the sun to the sun again, in 29 days 12 hours 44 minutes 3 seconds, which is exactly the time that she takes to go round her orbit from new moon to new moon; at what rate *per* hour are the inhabitants (if any) of her equatorial parts carried by this rotation, the moon's diameter being 2144 miles?

14. How many degrees does the motion of the moon exceed the apparent motion of the sun in 24 hours?

15. Find on what day, in any given month, the moon is eight days old, and then find her longitude for that day.

16. Travelling in an unknown latitude I found, by chance, an old horizontal dial, the hour-lines of which were so defaced by time that I could only discover those of IV. and V., and found their distance to be exactly 21 degrees; pray, what latitude was the dial made for?

17. Required the duration of twilight at the south pole?

18. How far must an inhabitant of London travel southward to lose sight of Aldebaran?

19. What is the elevation of the north polar star above the horizon of Calcutta?

20. Lord Nelson beat the French fleet near latitude 31 deg. 11 min. north, longitude 30 deg. 22 min. east; point out the place on the globe?

21. What is the sun's altitude at three o'clock in the afternoon at Philadelphia on the 7th of May?

22. What is the length of the day at London on the 26th of July, and how many degrees must the sun's declination be diminished to make the day an hour shorter?

23. At what hour does the sun first make his appearance at Petersburgh on the 4th of June?

24. At what rate *per* hour are the inhabitants of Botany Bay carried from west to east by the rotation of the earth on its axis?

25. When Arcturus is 30 deg. above the horizon of London, and eastward of the meridian, on the 5th of November, what o'clock is it?

26. Describe an horizontal dial for the latitude of Washington?

27. Describe a vertical dial facing the south for the latitude of Edinburgh?

28. What is the moon's greatest altitude to the inhabitants of Dublin?

29. What is the sun's greatest altitude at the southern extremity of Patagonia?

30. At what hour at London, on the 15th of August, will the Pleiades be on the meridian of Philadelphia?

31. If a comet, whose longitude was 4 signs 5 deg., and latitude 44 deg. north, appeared in Ursa-Major, in what part of the constellation was it?

32. On what point of the compass does the sun set at Madrid, when constant twilight begins at London?

33. What is the difference between the duration of twilight at Petersburgh and Calcutta, on the 1st of February?

34. How much longer is the 10th of December at Madras than at Archangel?

35. How much longer is the 5th of May at Archangel than at Madras?

36. When it is two o'clock in the afternoon at London, on the 15th of February, to what places is the sun rising and setting, and where is it noon?

37. Whether does the sun shine over the north or south pole on the 17th of April, and how far?

38. At what hour on the 18th of April will the sun's altitude, and azimuth from the east towards the south, be each 40 deg. at London?

39. Which way must a ship steer from Rio Janeiro to the Cape of Good Hope?

40. Are the clocks at Philadelphia faster or slower than those at London, and how much?

41. Are the clocks at Calcutta faster or slower than the clocks at London, and how much?

42. What is the difference of latitude between Copenhagen and Venice?

43. There is a place in latitude 31 deg. 11 min. north, situated, by an angle of position, south-east by east ½ east from London; what place is that, and how far is it from London in English miles?

44. On the 6th of October, 1844, the right ascension

of Venus was 9 deg. 56 min., declination 11 deg. 37 min. north; did Venus rise before or after the sun, and how much?

45. On the 9th of September, 1845, the right ascension of Venus was 13 deg. 5 min., declination 6 deg. 30 min. south; did Venus rise before or after the sun, and how much?

46. On the 26th of December, 1845, the right ascension of the planet Jupiter was 1 deg. 57 min. declination 10 deg. 37 min. north; at what hour did he rise, come to the meridian, and set at London?

47. On the 1st of January, 1846, the moon's right ascension at noon was 22 hrs. 4 min., declination 6 deg. 39 min. south; required her setting amplitude at London, and the hour and azimuth, when she is 25 deg. above the horizon?

48. The moon's right ascension on the 5th of November, 1845, at midnight, was 20 hrs. 18 min., declination 14 deg. 23 min. south; required the time of her rising, coming to the meridian, and setting at London, and the time of high water at London Bridge?

49. To what places of the earth was the moon vertical on the 7th of February, 1845, her right ascension at midnight being 12 hrs. 11 min.; and declination 6 deg. 50 min. south?

50. On the 1st of January, 1845, the moon's ascending node was 8 signs 12 deg. 52 min.; where was the descending node?

51. The moon's declination at midnight, on the 1st of November, 1845, was 16 deg. 18 min. south; to what places of the earth was she vertical?

52. What stars are constantly above the horizon of Copenhagen?

53. I observed the altitude of Betelgeux to be 19 deg., and that of Aldebaran 40 deg.; they both appeared in the same azimuth, viz. exactly east; what latitude was I in?

54. In what latitude is Aldebaran on the meridian when β in the Lion's tail is rising?

55. In what latitude is Rigel setting when Regulus is on the meridian?

56. In what latitude are the pointers in the Great Bear on the meridian when Vega is rising?

57. In latitude 79 deg. north, on the 1st of February, at what hour will Procyon and Regulus have the same altitude?

58. At what hour on the 10th of February will Capella and Procyon have the same azimuth at London?

59. On the 10th of November at eight o'clock in the evening, Bellatrix in the left shoulder of Orion was rising: what was the latitude of the place?

60. On the 16th of February, Arcturus rose at eight o'clock in the evening; what was the latitude?

61. At what hour of the night, on the 16th of February, will the altitude of Regulus be 28 deg. at London?

62. Required the altitude and azimuth of Markab in Pegasus, at London, on the 21st of September, at nine o'clock in the evening?

63. On what day of the month, and in what month, will the pointers of the Great Bear be on the meridian of London at midnight?

64. What inhabitants of the earth have the greatest portion of moonlight?

65. On what day of the year will Altair, in the Eagle, come to the meridian of London with the sun?

66. In what latitude north is the length of the longest day eleven times that of the shortest?

67. In what latitude south is the longest day eighteen hours?

68. At what time does the morning twilight begin, and what time does the evening twilight end, at Philadelphia, on the 15th of January?

69. When it is four o'clock in the afternoon at London, on the 4th of June, where is it twilight?

70. Required the antipodes of Cape Horn?

71. Required the periœci of Philadelphia?

72. Required the antœci of the Sandwich Islands?

73. What is the angle of position between London and Jerusalem?

74. Required the nearest distance between London and Alexandria, in English and in geographical miles?

75. In what latitude north does the sun begin to shine constantly on the 10th of April?

76. How long does the sun shine without setting at the north pole; and what is the duration of dark night?

77. Where is the sun vertical when it is midnight at Dublin on the 15th of July?

78. When it is five o'clock in the evening at Philadelphia, *where is it* midnight, and where is it noon?

79. What places have the same hours of the day as Edinburgh?

80. What places have opposite hours to the respective capitals of Europe?

81. At what hour at London is the sun due east at the time of the equinoxes?

82. At what hour at London is the sun due east at the time of the solstices?

83. In what climates are the following places situated, viz. Philadelphia, Madrid, Drontheim, Trincomalé, Calcutta, and Astracan?

84. On what day of the year does Regulus rise heliacally at London?

85. On what day of the year does Betelgeux set heliacally at London?

86. What stars set acronically at London on the 24th of December?

87. What stars rise acronically at London on the 12th of December?

88. In what latitude north do the bright stars in the head of the Dolphin, and Altair in the Eagle, rise at the same hour?

89. In what latitude north do Capella and Castor set at the same hour, and what is the difference of time between their coming to the meridian?

90. What stars rise cosmically at London on the 7th of December?

91. What stars set cosmically at London on the 10th of December?

92. What degrees of the ecliptic and equinoctial rise with Aldebaran at London?

93. On what day of the year does Arcturus come to the meridian of London, at two o'clock in the morning?

94. On what day of the year does Regulus come to the meridian of London, at nine o'clock in the evening?

95. At what time does Vega in Lyra come to the meridian of London, on the 18th of August?

96. Trace out the galaxy or milky-way on the celestial globe.

97. If the meridian altitude of the sun on the 7th of June be 50°, and south of the observer, what is the latitude of the place?

98. Required the sun's right and oblique ascension at London at the equinoxes?

99. Required the sun's right ascension, oblique ascension, ascensional difference, and time of rising and setting at London, on the 5th of May?

100. If the sun's rising amplitude on the 7th of June be 24° to the northward of the east, what is the latitude of the place?

101. What stars have nearly the following degrees of right ascensions and declinations?

7° 10′ R.A. 29° 45′ D.N.	162° 49′ R.A. 62° 50′ D.N.
14 38 R.A. 34 33 D.N.	244 17 R.A. 25 58 D.S.
135 59 R.A. 3 10 D.N.	238 27 R.A. 19 15 D.S.

102. Describe an horizontal sun-dial, for the latitude of Edinburgh?

103. What is the length of the day on February 14th at London, and how much must the sun's declination decrease to make the day an hour longer?

104. What hour is it at London when it is 17 minutes past 4 in the evening at Jerusalem?

105. On the 21st of June the sun's altitude was observed to be 46 deg. 25 min., and his azimuth 112 deg. 59 min. from the north towards the east, at London; what was the hour of the day?

106. Given the sun's declination 17 deg. 2 min. north, and increasing; to find the sun's longitude, right ascension, and the angle formed between the ecliptic and the meridian passing through the sun?

107. Given the sun's right ascension 225 deg. 18 min. to find his longitude, declination, and the angle formed between the ecliptic and the meridian passing through the sun?

108. Given the sun's longitude 26 deg. 9 min. in ♉; to find his declination, right ascension, and the angle formed between the ecliptic and the meridian passing through the sun?

109. Given the sun's amplitude 39 deg. 50 min. from the east towards the north, and his declination 23½ deg. north; to find the latitude of the place, the time of the sun's rising and setting, and the length of the day and night?

110. At what time on the 1st of April will Arcturus appear upon the 6 o'clock hour-line at London, and what will his altitude and azimuth be at that time?

111. Required the altitude of the sun, and the hour he will appear due east at London, on the 20th of May?

112. At what hours will Arcturus appear due east and west at London, on the 2nd of April, and what will its altitude be?

113. At London, the sun's altitude was observed to be 25 deg. 30 min. when on the prime vertical; required his declination, and the hour of the day?

114. On the 12th of April, 1845, the moon's right ascension at midnight was 6 hrs. 10 min., and her declination 20 deg. 20 min. north; required her distance from Regulus, Procyon, and Betelguex, at that time?

115. The distance of a comet from Sirius was observed to be 66 deg., and from Procyon 51 deg. 6 min.; the comet was westward of Sirius; required its latitude and longitude?

116. Find the Golden Number, the Epact, Sunday Letter, the Number of Direction, the Paschal full moon, and Easter day, for the years 1843, 1844, and 1845, distinguishing the leap years.

117. The declination of γ in the head of Draco is 51 deg. 30 min. north; to what places will it be vertical when it comes to their respective meridians?

118. When is it four o'clock in the evening at London on the 4th of May, to what places is the sun rising and setting, where is it noon and midnight, and to what place is the sun vertical?

119. At what time does the sun rise and set at the North Cape, on the north of Lapland, on the 5th of April, and what is the length of the day and night?

120. At what time does the sun rise at the Shetland Islands when it sets at four o'clock in the afternoon at Cape Horn?

121. Walking in Kensington Gardens on the 17th of May, it was 12 o'clock by the sun-dial, and wanted eight minutes to twelve by my watch; was my watch right?

122. If the sun set at nine o'clock, at what time does it rise, and what is the length of the day and night?

123. Where is the sun vertical when it is five o'clock in the morning at London on the 15th of May?

124. At what hour does day break at London on the 5th of April?

125. If the moon was 22 days old on the 27th of June,

1845, at what time did she rise, culminate, and set at London?

126. On what day of the month, and in what month, does the sun rise 24 deg. to the north of the east at London?

127. When the sun is rising to the inhabitants of London on the 8th of May, where is it setting?

128. When the sun is setting to the inhabitants of Calcutta on the 18th of March, where is it midnight?

129. What is the difference between the circumference of the earth at the equator and at Petersburgh, in English miles?

130. At what hour does the sun rise at Barbadoes when constant twilight begins at Dublin?

131. When the sun is rising at Owhyhee on the 18th of May, where is it noon?

132. At what hour does the sun rise at London when it sets at seven o'clock at Petersburgh?

133. How high is the north polar star above the horizon of Quebec?

134. How many English miles must an inhabitant of London travel southward, that the meridian altitude of the north polar star may be diminished 25 deg.?

135. How many English miles must I sail or travel westward from London that my watch may be seven hours too fast?

136. What place of the earth has the sun in the zenith, when it is seven o'clock in the morning at London, on the 25th of April?

137. On what day of the month, and in what month, is the sun's amplitude at London equal to one-third of the latitude?

138. On what month and day is the sun's amplitude at London equal to the latitude of Kingston, in Jamaica?

139. If the moon was 25 days old on the 3rd of April, 1845, what is her longitude?

140. If the highest point of Mont Blanc be 5101 yards above the level of the sea, what would be its altitude on a globe of 18 inches in diameter?

141. If the polar diameter of the earth be to the equatorial diameter as 229 is to 230, what would the polar diameter of a three-inch globe be, if constructed on this principle?

142. What inhabitants of the earth, in the course of 12 *hours, will* be in the same situation as their antipodes?

143. On what day of the year at London is the twilight 8 hours long?

144. At what time does the sun rise and set at London, when the inhabitants of the north-pole begin to have dark night?

145. At what hour does the sun set at the Cape of Good Hope, when total darkness ends at the north pole?

146. What is the moon's longitude if full moon happened on the 22nd of April, 1845?

147. Does the sun ever rise and set at the north pole?

148. At what hour of the day, on the 15th of April, will a person at London have his shadow the shortest possible?

149. If the precession of the equinoxes be 50¼ seconds in a year, how many years will elapse before the constellation Aries will coincide with the solstitial colure?

150. If the obliquity of the ecliptic should continually diminish at the rate of 0·457 seconds in a year, as stated by Bessel, how many years will elapse from the 1st of January, 1845, when the obliquity of the ecliptic was 23° 27′ 34·23″ before the ecliptic will coincide with the equinoctial?

151. Required the duration of dark night at the south of Nova Zembla?

152. When constant twilight ends at Petersburgh, where is the day 18 hours long?

153. At what hour does the sun set at Constantinople, when it rises 12° to the north of the east?

154. What is the difference between a solar and a sidereal year, and what does that difference arise from?

155. What is the difference between the length of a natural or astronomical day and a sidereal day, and how does the difference arise?

156. Required the difference between the length of the longest day at Cape Horn and at Edinburgh?

157. If one man were to travel eight miles a day westward round the earth at the equator, and another two miles a day westward round it in the latitude of 80 deg. north; in how many days would each of them return to the place whence he set out?

158. If a pole of 18 feet in length be placed perpendicular to the horizon of London on the 15th of July, and another exactly of the same length be placed in a similar manner at Edinburgh, which will cast the longer shadow at noon?

159. If the moon be in 29 deg. of Leo at the time of new

moon, what sign and degree will she be in when she is five days old?

160. What is the duration of constant day or twilight at the north of Spitzbergen?

161. What place upon the globe has the greatest longitude, the least longitude, no longitude, and every longitude?

162. In what latitude is the length of the longest day, to the length of the shortest, in the ratio of 3 to 2?

163. If a man of 6 feet high were to travel round the earth, how much farther would his head go than his feet?

164. On what day of the week did the 10th of January fall in the year 1845?

165. At what hour in the afternoon, London time, on the 21st of June, will the shadow of a pole 10 feet high at Barbadoes, be the same length as the meridional shadow of a similar pole at London on the same day?

166. One end of a wall declines 30 degrees from the east towards the north, and the other end 60 degrees from the south towards the west in latitude 51° 30′ N., at what hour on the 21st of June does the sun begin to shine on the south of the wall, and at what hour does it leave it?

167. The south wall of a church declines 12° 30′ towards the east, in latitude 52° N., against which a vertical dial is fixed; for how many hours will the sun shine upon that dial on the 10th of May?

168. A clock, with a pendulum that beats seconds, and kept true time on the surface of the earth, was carried to the top of a mountain, and there lost 3 seconds in an hour, what was the height of the mountain?

CHAPTER II.

A Collection of Questions, with References to the Pages where the Answers will be found; designed as an Assistant to the Tutor in the examination of the Student.*

1. How many kinds of artificial globes are there?

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* Though a reference be given to the pages where the answers to each question may be found; yet, perhaps, it would be better for the student not to learn the answers by heart, verbatim from the book; but to frame an answer himself, from an attentive perusal of his lesson: by which *means the* understanding will be called into exercise as well as the *memory.*

2. What does the surface of the terrestrial globe represent, and which way is its diurnal motion? (page 1.)

3. What does the surface of the celestial globe exhibit, which way is its diurnal motion, and where is the student supposed to be situated when using it?

I. GREAT CIRCLES ON THE TERRESTRIAL GLOBE.

1. What is a GREAT CIRCLE, and how many are there drawn on the terrestrial globe? (*Definition* 6, page 2.)

2. What is the equator, and what is its use? (*Def.* 10. page 3.)

3. What are the meridians, and how many are drawn on the terrestrial globe? (*Def.* 8, page 2.)

4. What is the first meridian? (*Def.* 9, page 3.)

5. What is the ecliptic, and where is it situated? (*Def.* 11, page 3.)

6. What are the colures, and into how many parts do they divide the ecliptic? (*Def.* 14, page 4.)

7. What are the hour-circles, and how are they drawn on the globe? (*Def.* 50, page 11.)

8. What hour-circle is called the six o'clock hour-line? (*Def.* 51, page 11.)

9. What are the azimuth or vertical circles, and what is their use? (*Def.* 43, page 10.)

10. What is the prime vertical? (*Def.* 44, page 10.)

II. SMALL CIRCLES ON THE TERRESTRIAL GLOBE.

1. What is a SMALL CIRCLE, and how many are generally drawn on the terrestrial globe? (*Def.* 7, page 2.)

2. What are the tropics, and how far do they extend from the equator, &c.? (*Def.* 16, page 5.)

3. What are the polar circles, and where are they situated? (*Def.* 17, page 5.)

4. What are the parallels of latitude, and how many are generally drawn on the terrestrial globe? (*Def.* 18, page 5.)

5. What circles are called Almacanters? (*Def.* 40, page 10.)

III. GREAT CIRCLES ON THE CELESTIAL GLOBE.

1. How many GREAT CIRCLES are drawn on the celestial globe?

2. The lines of terrestrial longitude are perpendicular to the equator, on the terrestrial globe, and all meet in the poles of the world; to what great circle on the globe are the lines of celestial longitude perpendicular, and on what points of the globe do they all meet?

3. What are the colures, and into how many parts do they divide the ecliptic? (*Def.* 14, page 4.)

4. What is the equinoctial, and what is its use? (*Def.* 10, page 3.)

5. What is the ecliptic, and where is it situated? (*Def.* 11, page 3.)

6. What is the zodiac, and into how many parts is it divided? (*Def.* 12, page 3.)

7. What are the signs of the zodiac, and how are they marked? (*Def.* 13, page 3.)

8. Which are the spring, summer, autumnal, and winter signs; and on what days does the sun enter them? (*Def.* 13, page 4.)

9. Which are the ascending and descending signs? (*Def.* 13, page 4.)

IV. SMALL CIRCLES ON THE CELESTIAL GLOBE.

1. How many SMALL CIRCLES are drawn on the celestial globe?

2. What are the tropics, and how far do they extend from the equinoctial? (*Def.* 16, page 5.)

3. What are the polar circles, and where are they situated? (*Def.* 17, page 5.)

4. What are the parallels of celestial latitude? (*Def.* 41, page 10.)

5. What are the parallels of declination? (*Def.* 42, page 10.)

V. THE BRASS MERIDIAN, AND OTHER APPENDAGES TO THE GLOBES.

1. What is the brazen meridian, and how is it divided and numbered? (*Def.* 5, page 2.)

2. What is the axis of the earth, and how is it represented by the artificial globes? (*Def.* 3, page 1.)

3. What are the poles of the world? (*Def.* 4, page 2.)

4. What are the hour-circles, and how are they divided? (*Def.* 19, page 5.)

5. What is the horizon, and what is the distinction between the rational and sensible horizon? (*Def.* 20, 21, and 22, pages 5 and 6.)

6. What is the wooden horizon, and how is it divided? (*Def.* 23, page 6.)

7. What is the mariner's compass, how is it divided, and what is the use of it on the globe? (*Def.* 33, 34, and note, pages 8 and 9.)

8. What is the quadrant of altitude, how is it divided, and what is its use? (*Def.* 37, page 9.)

VI. POINTS ON, AND BELONGING TO, THE GLOBES.

1. What is the pole of a circle? (*Def.* 29, page 7.)

2. What is the zenith, and of what circle is it the pole? (*Def.* 27, page 7.)

3. What is the nadir, and of what circle is it the pole? (*Def.* 28, page 7.)

4. What are the cardinal points of the horizon? (*Def.* 24, page 7.)

5. What are the cardinal points in the heavens? (*Def.* 25, page 7.)

6. What are the cardinal points of the ecliptic, and which are the cardinal signs? (*Def.* 26, page 7.)

7. What are the equinoctial points? (*Def.* 30, page 7.)

8. What are the solstitial points? (*Def.* 31, page 7.)

9. What is the culminating point of a star, or of a planet? (*Def.* 52, page 11.)

10. What are the poles of the ecliptic, how far are they from the poles of the world, and in what circles are they situated? (*Def.* 29, page 7.)

VII. LATITUDE AND LONGITUDE ON THE TERRESTRIAL GLOBE, THE DIVISION OF THE GLOBE INTO ZONES AND CLIMATES, THE POSITIONS OF THE SPHERE, THE SHADOWS AND POSITIONS OF THE INHABITANTS WITH RESPECT TO EACH OTHER.

1. What is the latitude of a place on the terrestrial globe? (*Def.* 35, page 9.)

2. What is the longitude of a place on the terrestrial globe? (*Def.* 38, page 10.)

3. What is a zone, and how many are there on the terrestrial globe? (*Def.* 70, page 17.)

4. What is the situation, and what is the extent of the torrid zone? (*Def.* 71, page 17.)

5. Where are the two temperate zones situated, and what is the extent of each? (*Def.* 72, page 18.)

6. Where are the two frigid zones situated, and what is the extent of each? (*Def.* 73, page 18.)

7. What is a climate, and how many are there on the globe? (*Def.* 69, page 15.)

8. Have all places in the same climate the same atmospherical temperature? (Chap. X. page 157.)

9. How many different positions of the sphere are there? (*Def.* 65, page 15.)

10. What is a right sphere, and what inhabitants of the globe have this position? (*Def.* 66, page 15; see likewise *Prob.* XXII. page 277.)

11. What is a parallel sphere, and what inhabitants of the globe have this position? (*Def.* 67, page 15; and *Prob.* XXII. page 278, &c.)

12. What is an oblique sphere, and what inhabitants of the globe have this position? (*Def.* 68, page 15; and *Prob.* XXII. page 280, &c.)

13. What parts of the globe do the AMPHISCII inhabit, and why are they so called? (*Def.* 74, page 18.)

14. When do the AMPHISCII obtain the name of ASCII?

15. What parts of the globe do the HETEROSCII inhabit, and why are they so called? (*Def.* 75, page 18.)

16. What parts of the globe do the PERISCII inhabit, and why are they so called? (*Def.* 76, page 18.)

17. What inhabitants are called ANTŒCI to each other, and what do you observe with respect to their latitudes, longitudes, hours, &c. (*Def.* 77, page 18.)

18. What inhabitants are called PERIŒCI to each other, and what is observed with respect to their latitudes, longitudes, hours, seasons, &c.? (*Def.* 78, page 18.)

19. What are the ANTIPODES, and what is observed with respect to their seasons of the year, &c.? (*Def.* 79, page 19.)

VIII. LATITUDES AND LONGITUDES OF THE STARS AND PLANETS ON THE CELESTIAL GLOBE, ETC., TOGETHER WITH THE POETICAL RISING AND SETTING OF THE STARS, ETC.

1. What is the latitude of a star or planet? (*Def.* 36, page 9.)
2. What is the longitude of a star or planet? (*Def.* 39, page 10.)
3. What are the fixed stars, and why are they so called? (*Def.* 89, page 23.)
4. What is a constellation, and how many are there on the celestial globe? (*Def.* 91, page 23; see the tables, pages 24, 25, and 26.)
5. What is meant by the poetical rising and setting of the stars? (*Def.* 90, page 23.)
6. When is a star said to rise and set cosmically?
7. When is a star said to rise and set acronically?
8. When is a star said to rise and set heliacally?
9. What is the Via Lactea, and through what constellations does it pass? (*Def.* 92, page 33.)
10. What kind of stars are termed nebulous? (*Def.* 93, page 33.)
11. How are the stars, which have not particular names, distinguished on the celestial globe? (*Def.* 94, page 33.)

IX. DEFINITIONS AND TERMS COMMON TO BOTH THE GLOBES.

1. What is the declination of the sun or star, or planet? (*Def.* 15, page 4.)
2. What is a hemisphere? (*Def.* 32, page 8.)
3. What is the altitude of any object in the heavens? (*Def.* 45, page 10.)
4. What is the meridian altitude of the sun, a star, or planet?
5. What is the zenith distance of a celestial object? (*Def.* 46, page 10.)
6. What is the polar distance of a celestial object? (*Def.* 47, page 11.)
7. What is the amplitude of a celestial object? (Def. 48, *page 11.)*

8. What is the azimuth of a celestial object? (*Def.* 49, page 11.)

9. What is the right ascension of the sun, or of a star, &c.? (*Def.* 80, page 19.)

10. What is the oblique ascension of the sun, or of a star, &c.? (*Def.* 81, page 19.)

11. What is the oblique descension of the sun, or of a star, &c.? (*Def.* 82, page 19.)

12. What is the ascensional or descensional difference? (*Def.* 83, page 19.)

X. TIME: YEARS, DAYS, ETC.

1. What is a solar or tropical year, and what is the length of it? (*Def.* 62, page 13.)

2. What is a sidereal year, and what is its duration? (*Def.* 63, page 14.)

3. What is an astronomical day? (*Def.* 58, page 12.)

4. What is a mean solar day? (*Def.* 57, page 12.)

5. What is a true solar day? (*Def.* 56, page 12.)

6. What is an artificial day? (*Def.* 59, page 13.)

7. What is a civil day? (*Def.* 60, page 13.)

8. What is a sidereal day? (*Def.* 61, page 13.)

9. What is meant by apparent noon, or apparent time? (*Def.* 53, page 12.)

10. What is true or mean noon? (*Def.* 54, page 12.)

11. What is the equation of time at noon? (*Def.* 55, page 12.)

12. What is a calendar? (page 234.)

13. What method of computing time is followed by most savage nations? What civilised nations employ a lunar chronology? What is the length of their year? (page 235.)

14. What chronology was used at Rome before the time of Julius Cæsar? What alterations did he make in the calendar? What was the yearly amount of error in his mode of reckoning?

15. By whom was this error corrected? When, and how? What alterations did he make to prevent the recurrence of such an error? (page 236.)

16. Give an account of the amount of error of the Gregorian calendar. By what additional correction might it be made more perfect? What would the amount of error be in that case?

17. When was the Gregorian calendar introduced into Germany? Into England? Why was it not earlier introduced into those countries? What rectification was then found necessary to correct the error accumulated in the existing calendar? What alteration was then made in the time of the year's commencement? (page 237.)

18. What European nations still adhere to the Julian calendar, or Old Style? By how many days do the dates of the Old Style at present differ from those of the new?

19. What is the cycle of the moon, and how is it found? (page 238.)

20. What is the epact, what is its use, and how is it found? (page 238.)

21. What is the cycle of the sun, how is it found, and to what use is it applied? (page 239.)

22. What is the number of direction, and how is Easter found by it? (page 240.)

23. How do you find the Paschal full moon and Easter by the epact? (page 240.)

24. What is the Roman Indiction, and how is it found? How do you find the Julian Period? (page 237.)

25. In what manner do you find the moon's age, the time of new moon, and the time of full moon, by the table, page 233?

XI. ASTRONOMICAL AND MISCELLANEOUS DEFINITIONS, ETC.

1. What do you understand by the precession of the equinoxes, and in what time do they make an entire revolution round the equinoctial? (*Def.* 64, page 14.)

2. What is the crepusculum or twilight, and what is the cause of it? (*Def.* 84, page 19.)

3. What is refraction, and whence does it arise? (*Def.* 85, pages 19, 20, 21.)

4. What is meant by the parallax of the celestial bodies? (*Def.* 86, page 22.)

5. What is an angle of position between two places? (*Def.* 87, page 22; and note, pages 260, 261.)

6. What are rhumbs and rhumb-lines? (*Def.* 88, page 22.)

7. What are the planets, and how many belong to the *solar system?* (*Def.* 95, page 34.)

8. What is the distinction between primary and secondary planets, and how many secondary planets belong to the solar system? (*Def.* 96 and 98, pages 34 and 35.)

9. What is the orbit of a planet? (*Def.* 99, page 35.) Of what figure are the orbits of the planets, and in what part of the figure is the sun placed? (page 204.)

10. What are the nodes of a planet? (*Def.* 100, page 35.)

11. What are the different aspects of the planets, and how many are there? (*Def.* 101, page 35.)

12. What are the syzygies and quadratures of the moon?

13. When is a planet's motion said to be direct, stationary, or retrograde? (*Def.* 102, 103, and 104, page 36.)

14. What is a digit? (*Def.* 105, page 36.)

15. What is the disc of the sun or moon? (*Def.* 106, page 36.)

16. What are the geocentric and heliocentric latitudes and longitudes of the planets? (*Def.* 107 and 108, page 36.)

17. When is a planet said to be in apogee? (*Def.* 109, page 36.)

18. When is a planet said to be in perigee? (*Def.* 110, page 36.)

19. What is the aphelion or higher apsis of a planet's orbit? (*Def.* 111, page 36.)

20. What is the perihelion or lower apsis of a planet's orbit? (*Def.* 112, page 36.)

21. What is the line of the apsides? (*Def.* 113, page 36.)

22. What is the eccentricity of the orbit of a planet? (*Def.* 114, page 36.)

23. What is the elongation of a planet? (*Def*, 119, page 37.)

24. What are the occultation and transit of a planet? (*Def.* 115 and 116, page 36.)

25. What is the cause of an eclipse of the sun?-(*Def.* 117, page 36.)

26. What is the cause of an eclipse of the moon? (*Def.* 118, page 37.)

27. What are the nocturnal and diurnal arcs described by the heavenly bodies? (*Def.* 121 and 120, page 37.)

28. What is the aberration of a star? (*Def.* 122, page 37.)

29. What are the centripetal and centrifugal forces? (*Def.* 123 and 124, page 38.)

30. What is gravity? (*Def.* 8, page 46.)

31. What is the vis inertiæ of a body? (*Def.* 9, page 48.)

32. What is matter, and what are its general properties? (*Def.* 1 and 2, page 42.)

33. What are extension, figure, and solidity? (*Def.* 3, 4, and 5, page 42.)

34. Can matter be divided *ad infinitum*? (*Def.* 6, page 44.)

35. What is motion, and what is the distinction between *absolute* and *relative* motion? (*Def.* 10, page 49.)

36. How is the velocity of a body measured, and what do you understand by the word force? (*Def.* 11 and 12, pages 50 and 51.)

37. What are Sir I. Newton's three laws of motion? (page 52.)

38. What is compound motion? (page 53.)

XII. OF THE STARS.

1. Enumerate the causes of the apparent motions of the fixed stars. (page 195.)

2. What star is at present the pole star? How far is it from the pole? When will it be nearest to the pole? (page 196.)

3. What effect has the precession of the equinoxes on the right ascension of stars? On their declination? On their latitude? On their longitude?

4. Explain the cause of precession. Why is it so called? By whom, and when, was it first observed? By whom was the cause of it discovered?

5. The inclination of the ecliptic to the equator is not absolutely constant: is it increasing or diminishing? At what rate? Within what limits is this variation confined? (page 197.)

6. Explain the phenomenon of nutation, and its cause.

7. What effect has the aberration of light upon the apparent position of a star? By whom were the phenomena of nutation and aberration first observed and explained?

8. Why have most of the fixed stars no apparent parallax? What is the parallax of 61 Cygni? Of α Lyræ? Of α Centauri? By whom were they discovered? Which is the *nearest of these* to us? At what distance from us is it?

How long does its light take in travelling to us? Do any of the fixed stars shine by the sun's light? Why so? (page 198.)

9. What is meant by multiple stars? Is this proximity in most cases actual or real? State some of Struve's calculations as to the proximity of double stars. As to that of triple stars. What proportion of the stars examined by him were found to be multiple stars? (pages 198, 199.)

10. What law has been observed to govern the motions of multiple stars? From what cause must such motion necessarily be derived? What inference do you draw from this? (page 199.)

11. State the periods of the double stars whose motions have been calculated. What is the longest period with which you are acquainted? Of how many stars does the multiple star, ε and 5 Lyræ, consist? Give some account of the motions of its constituent stars.

12. What are the colours of some of the most remarkable fixed stars? Are the constituents of the double stars usually the same or different in colour? A remarkable peculiarity is observed in the association of colours in many of the double stars: state what it is. Is this association of colours real, or does it arise from an optical delusion? Why so?

13. Several stars vary periodically in brightness: what law has been detected in these variations? Give an account of the variations of Algol. Of how many stars have the periods of variation been calculated? What is the shortest observed period? What the longest? (page 201.)

14. Stars, previously seen, have been known to disappear; stars, before unknown, to become visible: can you give any instances? Give a remarkable instance of variation in the brightness of a star as observed by Sir J. Herschel.

15. Have stars been ever known to change their colour? Give an instance. (page 202.)

16. What do you mean by an astral system? What is the form of the astral system to which we belong? What is the milky way? What is its appearance as seen from the earth? (page 190.) In what part of our astral system does our solar system lie?

17. What is Professor Mädler's theory respecting our astral system? How far is the supposed central sun from us? How long does its light take in travelling to the earth?

18. What are *nebulæ?* What are they supposed to consist of? How may their distance be calculated? How far are some of them supposed to be from us?

19. What was the theory of Sir W. Herschel and Laplace respecting the *nebulæ?*

XIII. THE SOLAR SYSTEM AND THE SUN.

1. Of what bodies is the solar system composed? (page 203.)

2. State the theories respecting the solar system; of (1) the earliest astronomers, (2) Thales, (3) Pythagoras, (4) Hipparchus, (5) Ptolemy, (6) Copernicus, (7) Tycho Brahe, (8) Kepler. (pages 203, 204.)

3. Which of these is the correct theory, and how and by whom was its correctness proved? (pages 204, 205.)

4. What reason is there for believing in the universality of the laws of motion and attraction? (page 205.)

5. In what direction do the planets move?

6. Give an illustration of the relative magnitudes of the sun and planets.

7. What reason is there for supposing that the planets do not shine by their own light? (page 206.)

8. What is the sun's distance from the earth, and how is it calculated?

9. What is the sun's diameter, and how is it calculated?

10. What is the period of the sun's rotation on its axis, and what is the inclination of its axis to the ecliptic?

11. Has the sun any other motion?

12. Give the proportions of the sun's volume, density, and mass to those of the earth. (pages 206, 207.)

13. Of what nature is the sun supposed to be? On what grounds is this opinion formed?

14. What is the zodiacal light? When is it visible, and what is the cause of it? (page 207.)

XIV. OF MERCURY ☿.

1. Give an account of the apparent path of Mercury in the heavens. What is his angle of greatest elongation from the sun? (pages 207, 208.)

2. What is the form of Mercury's real path, and how may it be deduced from an observation of his apparent path? (page 208.)

3. Where are the ascending and descending nodes of Mercury situated? What is meant by the *transit* of Mercury, and how often does it occur?

4. Give an explanation of the apparent motions and phases of the inferior planets. (pages 208, 209.)

5. What is meant by the *synodical* period of a planet? Give a formula for calculating the synodical, in terms of the sidereal, period of a planet. (page 218.) What is the synodical period of Mercury? His sidereal period? The inclination to the ecliptic, and the mean radius and eccentricity of his orbit? His mean rate of motion in his orbit? The time of his revolution on his axis? (page 209.)

6. Give the elements of Mercury in terms of the earth's elements.

XV. OF VENUS ♀.

1. By what names was Venus known to the ancients? (page 210.)

2. What is her angle of greatest elongation from the sun?

3. What is the inclination of her orbit to the ecliptic? Its mean radius? Its eccentricity? Her mean rate of motion in her orbit? Her sidereal and synodical periods? Her period of rotation? The inclination of her axis of rotation to the plane of her orbit?

4. Give the elements of Venus in terms of the earth's elements.

5. How often do the transits of Venus occur? When was the last? When will be the next?

6. How is the existence of an atmosphere round any heavenly body ascertained? Has Venus any atmosphere?

7. Do the seasons and the length of the days and nights of Venus vary more or less than those of the earth, and why? Has she much or little twilight, and why? (page 211.)

8. Are the irregularities on the surface of Venus great or small? How is their existence ascertained?

XVI. OF THE EARTH ⊕.

1. What is the figure of the earth? (page 57.)
2. Why is the earth represented by a globe? (page 64.)
3. What proofs have we that the earth is globular? (pages 58, 59.)
4. What would be the elevation of Chimboraço, the highest of the Andes mountains, on an artificial globe of 18 inches diameter? (page 59, the note.)
5. What is a spheroid, and how is it generated? (page 59, the note.)
6. What is the difference between the polar and equatorial diameters of the earth? (page 61, and the note.)
7. What is the length of a degree? (pages 62, 63, and the note.)
8. What is the use of finding the length of a degree, and how can the magnitude of the earth be determined thereby? (page 62.)
9. Who was the first person who measured the length of a degree with tolerable accuracy? (page 63.)
10. What is the length of a degree according to the French admeasurement? (page 63, the note.)
11. In what time does the earth revolve on its axis from west to east? (page 65, and *Def.* 61, page 14, and the note.)
12. What is the diameter of the earth; what is its circumference, and how are they determined? (pages 62, 63, and the note.)
13. What proofs can you give of the diurnal motion of the earth? (pages 65 and 66.)
14. How do you explain the phenomena of the apparent diurnal motion of the sun? (page 66.)
15. What proofs can you give of the annual motion of the earth? (page 67.)
16. What is the distance of the earth from the sun, and how is it calculated? (page 68, and the note.)
17. At what rate per hour does the earth travel round the sun? (page 69.)
18. At what rate per hour are the inhabitants of the equator carried from west to east by the revolution of the earth on its axis, and at what rate per hour are the inhabitants of London carried the same way?

19. How do you explain the motion of the earth round the sun? (page 70.)

20. How do you illustrate the phenomena of the different seasons of the year? (page 71.)

XVII. OF THE MOON ☽.

1. By what arguments can it be proved that the moon moves round the earth? (page 211.)

2. What is the form of the orbit in which the moon moves round the earth? Its magnitude? Its inclination to the plane of the ecliptic?

3. What is meant by the *evections* of the moon? Give some account of them, and of their cause. (page 212.)

4. What influence has the sun's attraction upon the moon's velocity in her orbit? Is this influence uniform or variable? Why so?

5. What is the length of the moon's sidereal period? Of her synodical period?

6. What is meant by the moon's nodical period? What is its length? What is the mean daily rate of motion of the moon's nodes, and in which direction does it take place? What is the period of a revolution of the moon's nodes? (page 213.)

7. What is meant by the moon's anomalistic period? Why is it so called? What is its length, and why does it differ from her sidereal period? What is the period of a revolution of the moon's apsides?

8. In what direction, and in what time, does the moon rotate on her axis? What is the inclination of that axis to the plane of her orbit? Does she always show exactly the same face to the earth? Why so?

9. What is meant by the moon's libration in longitude, and from what cause does it arise? Why is it so termed? (page 214.)

10. What is meant by the moon's libration in latitude? From what cause does it arise? Why is it so termed?

11. What is meant by the moon's diurnal libration? By what other name is it known?

12. Give an account of the moon's spheroidal libration, and its cause. Why is it so called? What appearance would the earth have, if viewed from the moon? (page 215.)

13. Give the elements of the moon in terms of those of the earth.

14. Has the moon any atmosphere? Are there any seas in the moon? What are the grounds of this opinion? Of what nature, form, and height are the mountains in the moon? To what changes are the seasons of the moon subject? What is the length of her days and nights? Has she any twilight? Why so? Is she supposed to be inhabited? (pages 215, 216.)

XVIII. OF MARS ♂.

1. On what grounds do we conclude that the distance of Mars from the sun is greater than that of the earth?

2. Give an explanation of the apparent motions of the superior planets. (pages 217, 218.)

3. What is the mean radius of the orbit of Mars? Its eccentricity? Its inclination to the plane of the ecliptic? The mean rate of motion of Mars in his orbit? His sidereal period? His synodical period?

4. What is the diameter of Mars? The proportion of his equatorial to his polar diameter? The period of his rotation? Its direction? The inclination of his axis to the plane of his orbit?

5. Give the elements of Mars in terms of the earth's elements.

6. Has Mars an atmosphere? What is the colour of the surface of the soil in Mars? What are the white spots round his poles supposed to be? What circumstance gives strength to this opinion? Give some account of the seasons of Mars, and the variation in the length of his days and nights. (page 219.)

XIX. OF THE TELESCOPIC PLANETS.

1. It was from the discovery of a certain law in the distances of planets from the sun that astronomers were induced to look for a planet between Mars and Jupiter: what is this law? By whom, and when was it discovered? Has it been verified by recent discoveries?

2. In what order, at what times, and by whom were the *telescopic planets* discovered? (page 220.)

3. Why are these bodies called the ultra-zodiacal planets? What are their several angles of inclination to the ecliptic?

4. What are their respective mean distances from the sun? Their periodical times?

5. Have the diameters of any of them been calculated? Are these calculations accurate? Why so? Have any of these bodies atmospheres?

6. What theory has been proposed respecting the telescopic planets? What grounds render this probable? (page 221.)

XX. OF JUPITER ♃, ETC.

1. What is the radius of Jupiter's orbit? Its eccentricity? Its inclination to the plane of the ecliptic? The mean rate of motion of Jupiter in his orbit? His sideréal period? His synodical period?

2. What is the diameter of Jupiter? The proportion of his equatorial to his polar diameter? The period of his rotation? The inclination of his axis to the plane of his orbit?

3. Give the elements of Jupiter in terms of the earth's elements.

4. How many satellites has Jupiter? What are their respective periods and mean distances from Jupiter? Their times of rotation on their axes? In what direction do they circulate round Jupiter? By whom were they discovered?

5. What use is made of their eclipses and occultations? What important discovery has been made by the observation of their eclipses? By whom? When? (page 222.)

6. What appearance do Jupiter's belts present, as seen from the earth? What are they supposed to be? Compare the rate of motion of a body on the surface of Jupiter's and the earth's equators. Of what is the surface of Jupiter composed? Are his seasons, &c., subject to much or little variation? Why so?

XXI. OF SATURN ♄, ETC.

1. What is the radius of Saturn's orbit? Its eccentricity? Its inclination to the plane of the ecliptic? The mean rate of motion of Mars in his orbit? His sidereal period? His synodical period?

2. What is the diameter of Saturn? The proportion of his equatorial to his polar diameter? His period of rotation? The inclination of his axis to the plane of his orbit? (page 223.)

3. Give the elements of Saturn in terms of the earth's elements.

4. How many satellites has Saturn? What are their mean distances from him? Their periods? Give some account of the form and inclination of their orbits?

5. In what order, when, and by whom were they discovered?

6. What is the inclination of Saturn's ring to the plane of his equator? Of how many belts does it consist? What are the spaces between the several belts? Between the ring and the planet? The whole breadth of the ring? Its thickness? In what periods do the rings revolve round Saturn?

7. What appearance does Saturn present as seen from the earth? Has he an atmosphere? Why so? What appearance does Saturn's ring present to the inhabitants of the planet? Give some account of the variation in his seasons, &c. (page 224.)

XXII. OF URANUS ♅, ETC.

1. By whom, and when was Uranus discovered? By what name was it called by its discoverer? Why was it termed Uranus?

2. What is the mean radius of the orbit of Uranus? Its eccentricity? Its inclination to the plane of the ecliptic? The mean rate of motion of Uranus in his orbit? His sidereal period? His synodical period?

3. What is the period of rotation of Uranus? The inclination of his axis to the plane of his orbit?

4. Give the elements of Uranus in terms of the earth's elements.

5. By how many satellites did Sir W. Herschel suppose Uranus to be attended? What values did he assign to their respective distances? To their periodic times? Which of them have been observed by other astronomers? What two remarkable peculiarities do they possess? (page 225.)

6. Is Uranus supposed to possess an atmosphere? Why so? Give some account of his seasons, &c.

XXIII. OF NEPTUNE, ♆, ETC.

1. What circumstance led astronomers to think that there was some other planet beyond Uranus? Give some account of the discovery of Neptune.

2. What is the mean radius of the orbit of Neptune? Its eccentricity? Its inclination to the plane of the ecliptic? The mean rate of motion of Neptune in his orbit? His sidereal period? His synodical period? The time of his diurnal rotation? The angle of inclination of his axis?

3. How many satellites of Neptune have, as yet, been discovered? By whom, and when? What is the period of Neptune's satellite? Its mean distance from the planet? The inclination of its orbit to the ecliptic? Its eccentricity? The time of the satellite's rotation on its axis? (page 226.)

4. What remarkable peculiarity has been observed in the brightness of Neptune's satellite? Has a similar peculiarity been remarked in any other satellite? To what cause is it to be attributed?

5. What is the diameter of Neptune's ring?

XXIV. OF COMETS.

1. How many comets have been accurately observed? How many have been identified as previously observed? What are their names and periods? Of what form are the orbits of comets?

2. What is meant by the *stability* of the planetary system? How is it produced? What is the cause of the instability of comets?

3. Of what do comets consist? Of what form are they? State some circumstances, proving the great tenuity of substance of comets. Does the same comet ever vary in form or magnitude? Give an instance. (page 227.)

XXV. OF THE PHASES OF THE MOON, AND OF ECLIPSES.

1. In what position is the moon invisible from the earth? In what position is her whole hemisphere visible? In what, half her hemisphere? What is meant by the moon's octants? In what positions is the moon's phase gibbous? In what

horned? In what direction are the moon's horns turned? (page 228.)

2. Explain the phenomenon of the "old moon under the new moon's arm." What is the French term for it?

3. For how many days in each month is the moon invisible? Give your reasons.

4. What are meant by the *umbra* and *penumbra* of the earth or moon? What is the form of the umbra? What of the penumbra? (page 229.)

5. Explain the cause of a solar eclipse. In what case is it total? In what partial? What is an annular eclipse, and in what cases does it occur? To how large a portion of the earth's surface at once may a total eclipse of the sun be visible? To how large a portion at once may the sun be partially eclipsed?

6. On what circumstances does the duration of a solar eclipse depend? Why so? What is the greatest possible length of an annular eclipse? What of a total eclipse? (page 230.)

7. How is an eclipse of the moon caused? In what position of the moon does it occur? Can there be an annular eclipse of the moon? Why so? Can a lunar eclipse be at the same time visible to some, and invisible to others? Why so?

8. On what circumstances does the length of a lunar eclipse depend? What is the greatest possible duration of a lunar eclipse? What of a total lunar eclipse?

9. Why are there not a lunar and solar eclipse every month? What is meant by the solar and lunar ecliptic limits? What is their extent?

10. What is the smallest possible number of solar eclipses in a year? Give your reasons. What is the greatest possible number? Why so? What is the smallest, and what the greatest, possible number of lunar eclipses in a year? State your reasons. (pages 231, 232.)

11. What is the smallest possible number of eclipses of both kinds in the course of a year? Give your reasons. What the greatest? What proportion of these are lunar, what solar, eclipses? State under what circumstances this can occur, and why this is the largest possible number.

12. What is the proportion of the number of solar, to that of lunar, eclipses? Are more solar eclipses or more

lunar eclipses visible on the average from the same place? Why so?

13. Give an explanation of the cycle of eclipses. By whom is it said to have been discovered? What is the origin of the term "Golden Number?"

N.B. *The Tutor may extend these questions to the Geographical Theorems, page* 42, *to Chap. V. VI. VII. VIII. and IX. Part I., and to Chap. I. II. and III. Part II.; also to the manner of solving the different problems, &c.*

AN

ETYMOLOGICAL TABLE

OF

THE PRINCIPAL SCIENTIFIC TERMS

MADE USE OF IN THE FOREGOING WORK.

ABERRATION, from (Lat.) *ab*, from, and *erro*, to wander.

Acronycal, from (Greek) *ακρον*, a point, and *νυξ*, night.

Aerolithes, from (Greek) *αηρ*, air, and *λιθος*, a stone.

Altitude, from (Lat.) *altitudo*, height.

Amphiscii, from (Greek) *αμφι*, both, *σκια*, a shadow.

Antarctic, from (Greek) *αντι*, opposite to, and *αρκτος*, a bear.

Antipodes, from (Greek) *αντι*, and *ποδες*, the feet.

Antœci, from (Greek) *αντι*, and *οικεω*, to dwell.

Aphelion, from (Greek) *απο*, from, and *ἥλιος*, the sun.

Apogee, from (Greek) *απο*, from, and *γη*, the earth.

Apsis, from (Greek) *αψις*, a bend, as of an arched roof, a ring, a wheel, &c.

Arctic, from (Greek) *αρκτος*, a bear.

Ascii, from (Greek) *α*, not, or without, and *σκια*, a shadow.

Astronomy, from (Greek) *αστηρ*, a star, and *νομος*, a law.

Atmosphere, from (Greek) *ατμος*, vapour, and *σφαιρα*, a sphere.

Axis, from (Lat.) *ago*, to act.

Celestial, from (Lat.) *cœlestis*, heavenly.

Centrifugal, from (Lat.) *centrum*, the centre, and *fugio*, I flee.

Centripetal, from (Lat.) *centrum*, and *peto*, I seek.

Colure, from (Greek) *κολουρος*, having the tail cut, mutilated.

Comet from (Greek) *κομη*, hair.

Constellation, from (Lat.) *con* (for *cum*), with, and stella, a star.

Cosmical, from (Greek) *κοσμος*, the world.

Dichotomised, from (Greek) διχοτομος, cut into two parts.
Digit, from (Lat.) *digitus*, a finger.
Disc, from (Greek) δισκος, a quoit.
Eccentricity, from (Greek) εκ, out of, and κεντρον, centre.
Eclipse, from (Greek) εκλειπω, to faint away, or disappear.
Equinox, from (Lat.) *æquus*, equal, and *nox*, night.
Focus, from (Lat.) *focus*, a fire-hearth.
Frigid, from (Lat.) *frigidus*, cold.
Geocentric, from (Greek) γη, the earth, and κεντρον, the centre.
Gibbous, from (Lat.) *gibbus*, protuberant, hunched.
Gravity, from (Lat.) *gravis*, heavy.
Heliacal, from (Greek) ἡλιος, the sun.
Heliocentric, from (Greek) ἡλιος, and κεντρον, the centre.
Hemisphere, from (Greek) ἡμισυς, half, and σφαιρα, a sphere.
Heteroscii, from (Greek) ἑτερος, deviating from, another, and σκια, a shadow.
Horizon, from (Greek) ὁριζω, to limit.
Latitude, from (Lat.) *latitudo*, breadth.
Longitude, from (Lat.) *longitudo*, length.
Matter, from (Lat.) *materia* (from *mater*, a mother).
Meridian, from (Lat.) *meri-dies*, mid-day.
Node, from (Lat.) *nodus*, a knot.
Orbit, from (Lat.) *orbita*, a track.
Penumbra, from (Lat.) *pene*, almost, and *umbra*, a shade or shadow.
Perigee, from (Greek) περι, about, near, and γη, the earth.
Perihelion, from (Greek) περι, and ἡλιος, the sun.
Periœci, from (Greek) περι, and οικεω, to dwell.
Periscii, from (Greek) περι, and σκια, a shadow.
Phases, from (Greek) φάσις, appearances exhibited by any body in its changes, as those of the moon.
Phenomenon, from (Greek) φαινομαι, to appear.
Planet, from (Greek) πλανητης, wandering.
Satellite, from (Lat.) *satelles*, an attendant.
Sidereal, from (Lat.) *sidus*, a star.
Solar, from (Lat.) *sol*, the sun.
Solstice, from (Lat.) *sol*, and *sisto*, to stand.
Synœci, from (Greek) συν, with, together, οικεω, to dwell.
Syzigies, from (Greek) συζυγια, union.
Terrestrial, from (Lat.) *terrestris*, earthly.
Torrid, from (Lat.) *torridus*, hot.
Tropic, from (Greek) τρεπω, to turn.
Umbra, from (Lat.) *umbra*, a shade or shadow.

Vernal, from (Lat.) *vernus*, belonging to the spring.
Zodiac, from (Greek) *ζωδιον*, an animal.
Zone, from (Greek) *ζωνη*, a girdle.

The following Words are of less perfect Etymology.

Almacantar, from *almokentor*, a word partly Arabic and partly Greek, and signifies a circle, having its centre in the same axis with another.
Azimuth, from *alsempt*, an Arabic word, signifying the point or mark.
Zenith and Nadir are also corruptions of two Arabic terms; the former signifying a point, and applied to the *vertical* point, or point over head, and the latter, the point opposite to the *vertex*.

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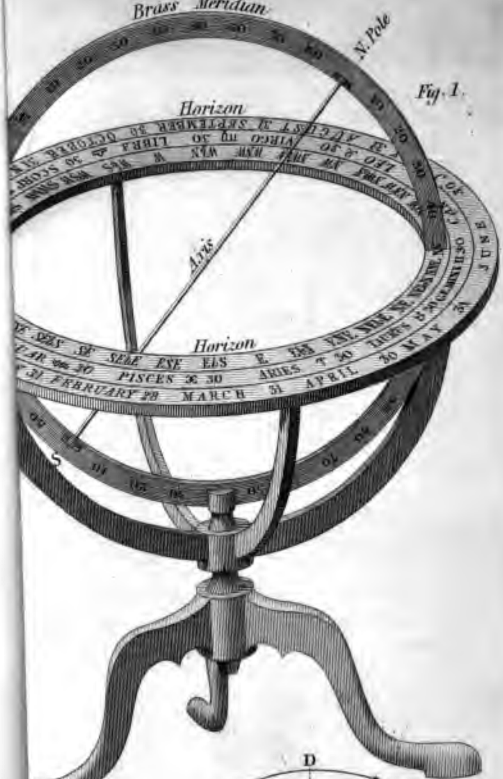

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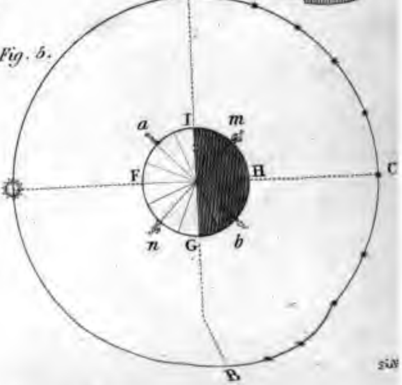

Fig. 5.

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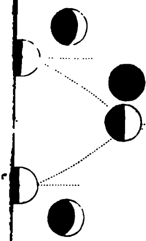

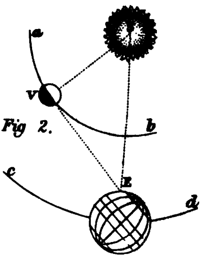

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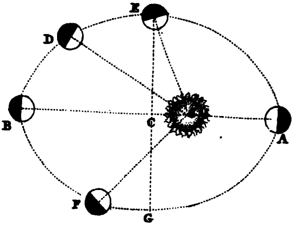

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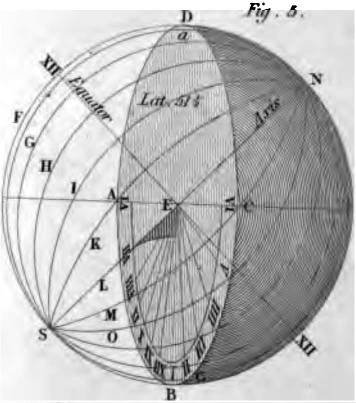

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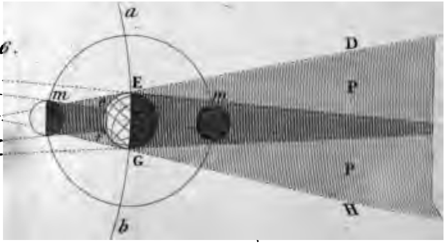

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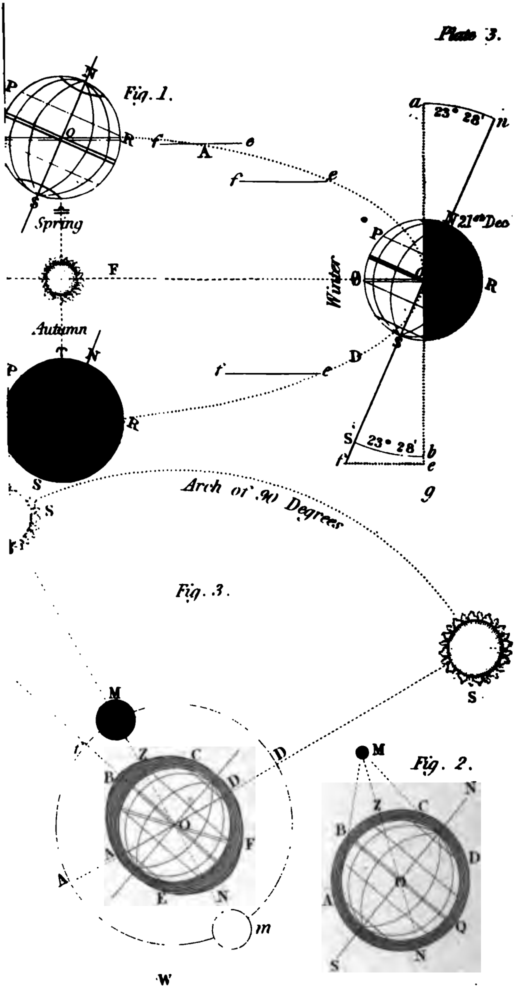

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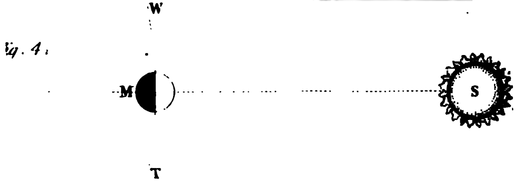

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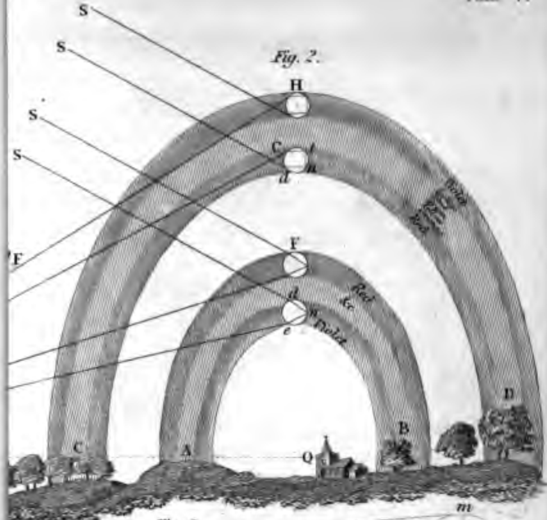

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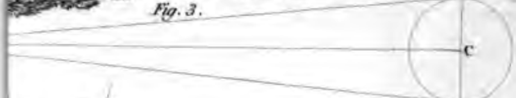

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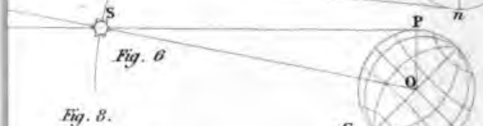

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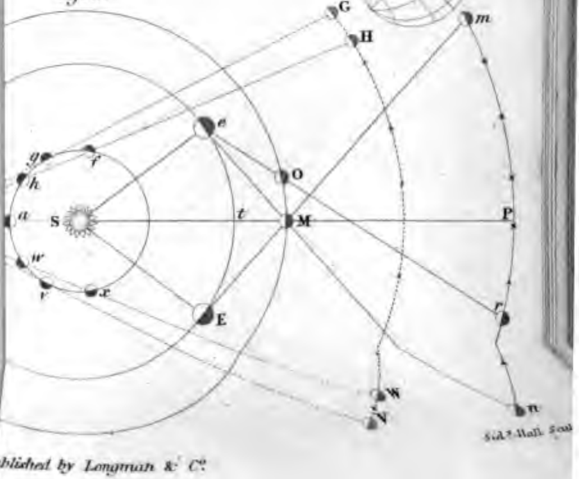

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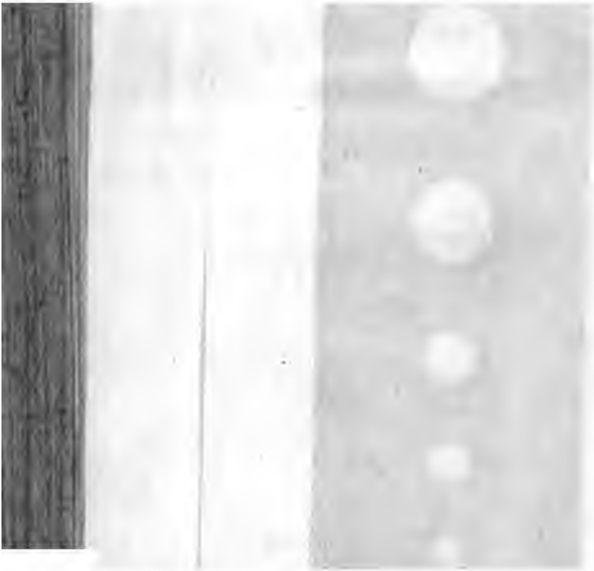

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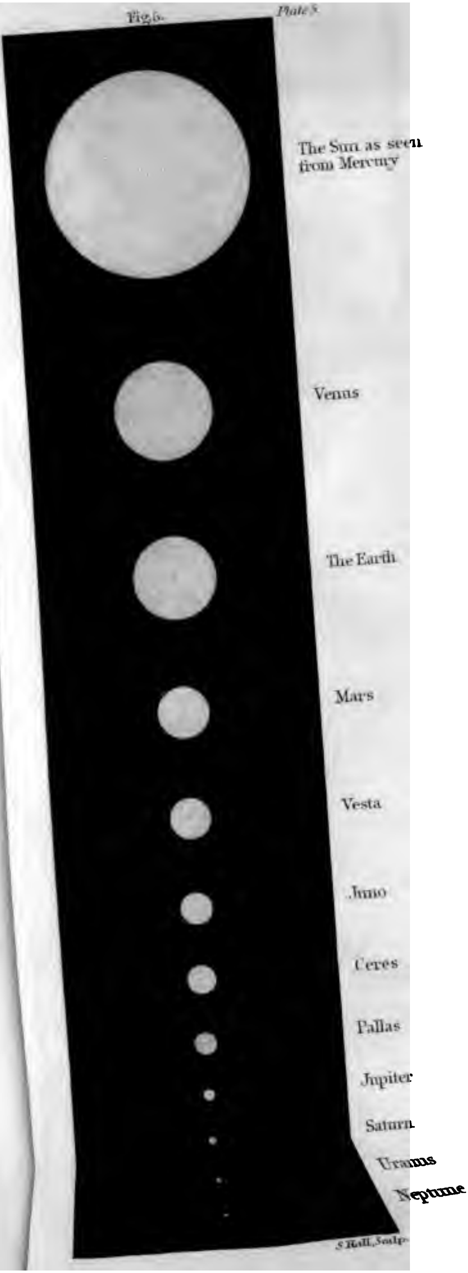

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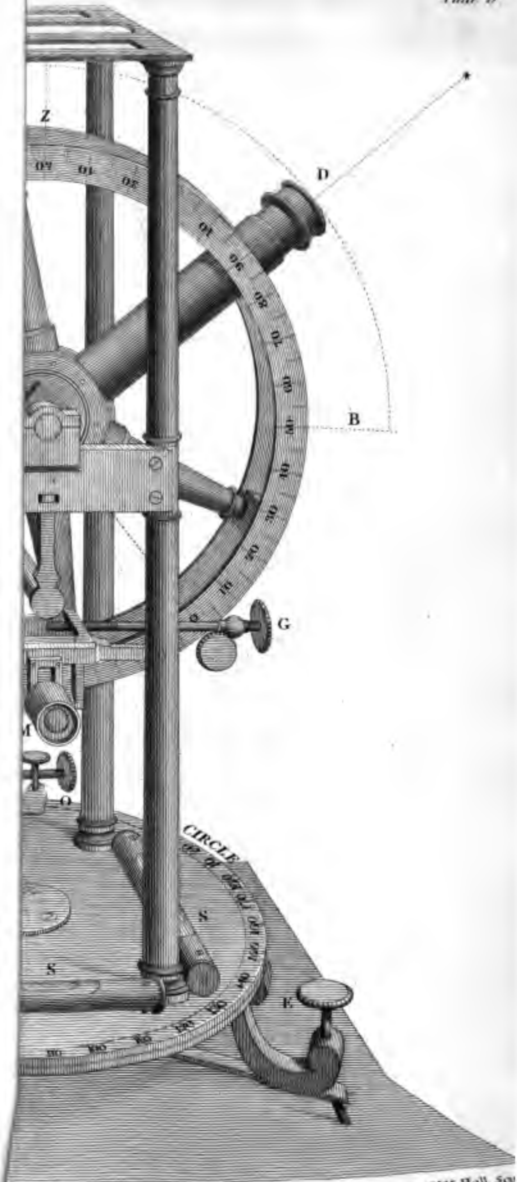

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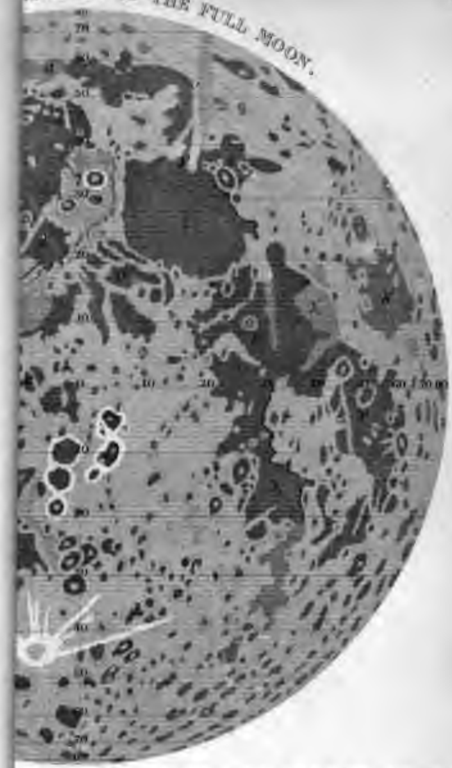

ots which were supposed by Riccioli and Hevelius to be Seas and named by them
nd to prevent confusion are not marked with any letter or figure but may be readily
bias Meyer) being given. The names throughout are according to Riccioli. See note to page 166.

λ	Palus Somni	Lake of Sleep
μ	Mare Tranquillitatis	Sea of Tranquillity
ν	Mare Fecunditatis	Sea of Fertility
ξ	Mare Nectaris	Sea of Nectar
ο	Mare Vaporum	Sea of Vapours
π	Sinus Æstuum	Bay of Tides
ς	Mare Nubium	Sea of Clouds
σ	Oceanus Procellarum	Ocean of Storms
τ	Mare Humorum	Sea of Moisture
υ	Sinus Epidemiarum	Bay of Epidemics

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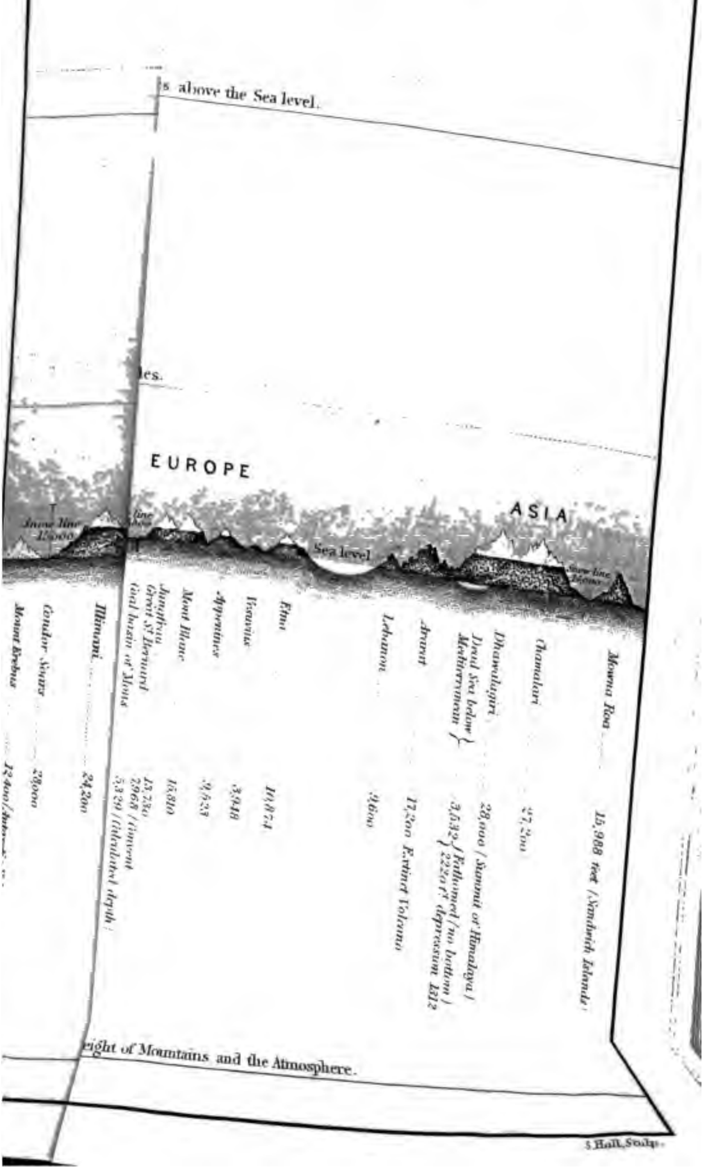
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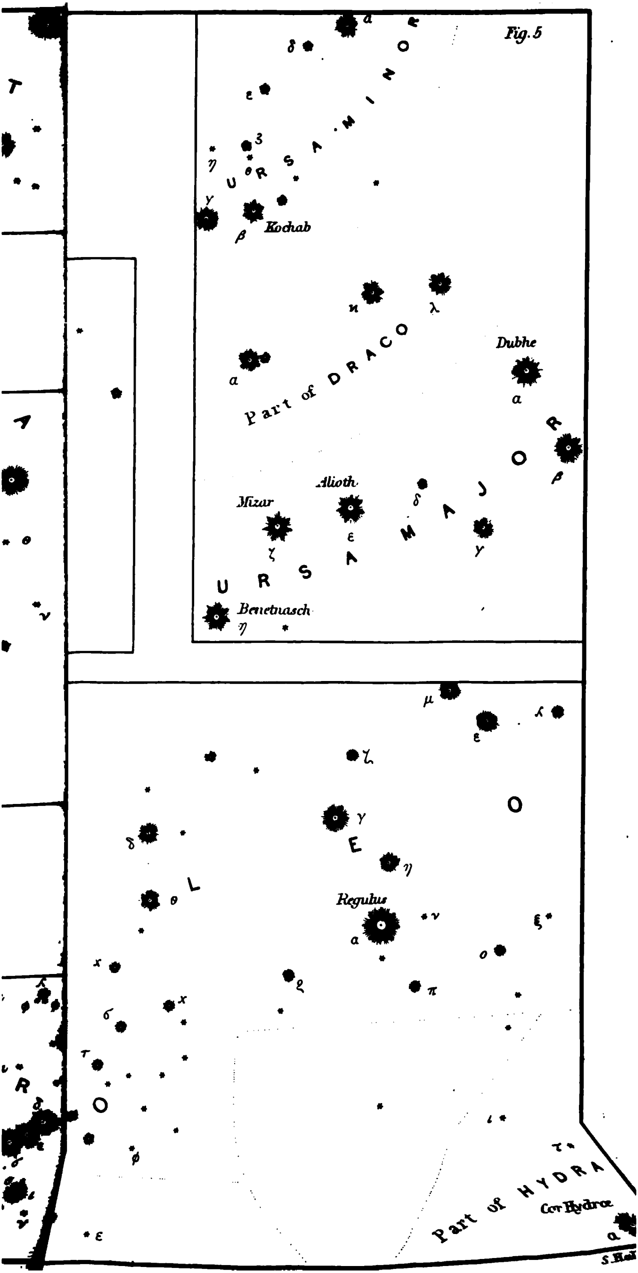
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